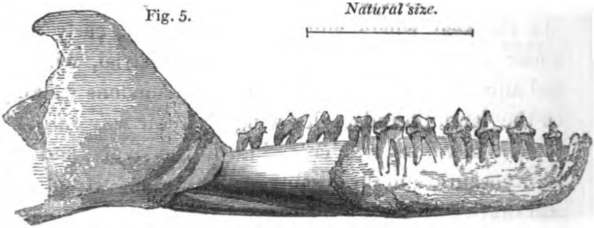
Fig. 5.



tives of the same class have yet been found in any other of the inferior or superior secondary strata, is a striking fact, and should serve as a warning to us against hasty generalizations, founded solely on negative evidence. So important an exception to a general rule may be perfectly consistent with the conclusion, that a small number only of mammalia inhabited European latitudes when our secondary rocks were formed; but it seems fatal to the theory of progressive development, or to the notion that the order of precedence in the creation of animals, considered chronologically, has precisely coincided with the order in which they would be ranked according to perfection or complexity of structure.

It has, however, been suggested that the marsupial order to which we have referred the fossil animals of Stonesfield, constitutes the lowest grade in the class Mammalia, and that this order, of which the brain is of more simple form, evinces an inferior degree of intelligence. If, therefore, in the oolitic period the marsupial tribes were the only warm-blooded quadrupeds which had as yet appeared upon our planet, the fact, it is said, confirms the theory which teaches that the creation of the more simple forms in each division of the animal kingdom preceded that of the more complex. But on how slender a support does this important conclusion hang! The Australian continent, so far as it has been hitherto explored, contains no indigenous quadrupeds save those of the marsupial order, with the exception of a few small rodents, while some neighbouring islands to the north, and even southern Africa, in the same latitude as Australia, abound in mammalia of every tribe except the marsupial.

Now we are entirely unable to explain on what

physiological or other laws this singular diversity in the habitations of living mammalia depends. If Europe at the period of the Stonesfield oolite was inhabited by marsupial quadrupeds only, it is still possible that higher orders of mammalia flourished contemporaneously in other lands; and, secondly, if no other tribes did then exist, we have no right to ascribe such a state of the animal creation to the immature age of the planet or of the animate world. There may be causes with which we are wholly unacquainted, which have stamped so peculiar a character on the recent fauna of Australia, and the general prevalence of an analogous state of things, might give rise every where to a like predominance of the marsupial tribes.

The strata of the Wealden, although of a later date than the oolite of Stonesfield, and although filled with the remains of large reptiles, both terrestrial and aquatic, besides birds and land plants, have not yielded as yet a single marsupial bone. Were we to assume on such scanty data that no warm-blooded quadrupeds were then to be found throughout the northern hemisphere, there would still remain a curious subject of speculation, whether the entire suppression of one important class of vertebrata, such as the mammiferous, and the great development of another, such as the reptilian, implies a departure from fixed and uniform rules governing the fluctuations of the animal world; such rules, for example, as appear from one century to another to determine the growth of certain tribes of plants and animals in arctic, and of other tribes in tropical regions.

In Australia, New Zealand, and many other parts of the southern hemisphere, where the indigenous land quadrupeds are comparatively few, and of small di-

mensions, the reptiles do not predominate in number or size. The deposits formed at the mouth of an Australian river, within the tropics, might contain the bones of only a few small marsupial animals, which, like those of Stonesfield, might hereafter be discovered with difficulty by geologists; but there would, at the same time, be no megalosauri and other fossil remains, showing that large saurians were plentiful on the land and in the waters, at a time when mammalia were scarce. This example, therefore, affords us no parallel to the state of the animal kingdom, supposed to have prevailed during the secondary periods, when a high temperature pervaded European latitudes.

It may nevertheless be advantageous to inquire how far existing anomalies in the geographical development of distinct classes of vertebrata may be comparable to former conditions of the animal creation brought to light by geology. Now in the Arctic regions, at present, reptiles are small, and sometimes wholly wanting, where birds, large land quadrupeds, and cetacea abound. We meet with bears, wolves, foxes, musk oxen, and deer, walrusses, seals, whales, and narwals, in regions of ice and snow, where the smallest snakes, efts, and frogs are rarely if ever seen.

A still more anomalous state of things presents itself in the southern hemisphere. Even in the temperate zone, between the latitudes 52° and 56° S., as, for example, in Terra del Fuego, as well as in the woody region immediately north of the Straits of Magellan, and in the Falkland Islands, no reptiles of any kind are met with, not even a snake, lizard, or frog; but in these same countries we find the guanaco (a kind of llama), a deer, the puma, a large species of fox, many

small rodentia, besides the seal and otter, together with the porpoise, whale, and other cetacea.

On what grand laws in the animal physiology these remarkable phenomena depend, cannot, in the present state of science, be conjectured; nor could we predict whether any opposite condition of the atmosphere, in respect to heat, moisture, and other circumstances, would bring about a state of animal life which might be called the converse of that above described, namely, a state in which reptiles of every size and order might abound, and mammalia disappear.

The nearest approximation to such a fauna is found in the Galapagos Archipelago. These islands, situated under the equator, and nearly 600 miles west of the coast of Peru, have been called "the land of reptiles," so great is the number of snakes, large tortoises, and lizards, which they support. Among the lizards, the first living species proper to the ocean has been discovered. Yet although some of these islands are from 3000 to 4000 feet high, and one of them 75 miles long, they contain, with the exception of one small mouse, no indigenous mammifer. In the neighbouring sea, however, there are seals, and several kinds of cetacea.*

It may be unreasonable to look for a nearer analogy between the fauna now existing in any part of the globe, and that which we can show to have prevailed when our secondary strata were deposited, because we must always recollect, that a mean annual temperature like that now experienced at the equator, co-existing with the unequal days and nights of European latitudes, was a state of things to which there is now

* Darwin's Journal, chap. xix. Elements of Geol. p. 394.

no counterpart, and must have produced climates wholly distinct from any now experienced in the globe. Consequently, the type of animal and vegetable existence required for such climates, might be expected to deviate almost as widely from those now established, as do the flora and fauna of our tropical differ from those of our arctic regions.

In the Tertiary strata. — The tertiary formations, as before stated, were deposited when the physical geography of the northern hemisphere had been entirely altered. Large inland lakes had become numerous, as in central France and other countries. There were gulfs of the sea, into which considerable rivers emptied themselves, and where strata like those of the Paris basin were accumulated. There were also littoral formations in progress, such as are indicated by the *Faluns* of the Loire, and the English *Crag*.

The proximity, therefore, of large tracts of dry land to the seas and lakes then existing, may, in a great measure, explain why the remains of land animals, so rare in the older strata, are not uncommon in these more modern deposits. Yet even these have sometimes proved entirely destitute of mammiferous relics, for years after they had become celebrated for the abundance of their fossil testacea, fish, and reptiles. Thus the calcaire grossier, a marine limestone of the district round Paris, had afforded to collectors more than 1100 species of shells, besides many zoophytes, echinodermata, and the teeth of fish, before the bones of one or two land quadrupeds were met with in the same rock. The strata called London and plastic clay in England, have been studied for more than half a century, and about 400 species of shells, 50 or more of fish, besides several kinds of chelonian and

saurian reptiles, were known before a single mammifer was detected. At length, in the year 1839, there were found in this formation the remains of a monkey, an opossum, a bat *, and a species of the extinct genus Hyracotherium, allied to the pecari or hog tribe.

If we examine the strata above the London clay in England, we first meet with mammiferous remains in the Isle of Wight, in beds also belonging to the Eocene epoch, such as the remains of the Palæotherium, Anoplotherium, and other extinct quadrupeds, agreeing very closely with those first found by Cuvier, near Paris, in strata of the same age, and of similar freshwater origin.

Next in the ascending series in Great Britain we arrive at the coralline crag of Suffolk, a marine Miocene stratum, which has yielded three or four hundred species of shells, of which about 20 per cent. are recent, besides many corals, echini, foraminifera, and fish, but as yet no relic decidedly mammalian.

In the shelly sand, provincially termed "Red Crag," in Suffolk, which immediately succeeds the coralline, constituting a newer member of the Miocene series, about 250 species of shells have been recognized, of which about 30 per cent. are recent. They are associated with numerous teeth of fish, but no signs of a warm-blooded quadruped had been detected until 1839, when the teeth of a leopard, bear, hog, and a species of ruminant, were found at Newbourn in Suffolk, under circumstances which leave scarcely any doubt that they were of the age of the Red Crag.†

* Taylor's Annals of Nat. Hist. Nov. 1839.

† See notice by the author and Professor Owen, Taylor's Annals of Nat. Hist. Nov. 1839.

Of a still newer date is the Norwich Crag, a fluvio-marine deposit of the Pliocene epoch, containing a mixture of marine, fluviatile, and land shells, of which about 60 per cent. are recent. These beds, since the time of their first investigation, have yielded a supply of mammalian bones of the genera mastodon, elephant, rhinoceros, pig, horse, deer, ox, and others, the bodies of which may have been washed down into the sea by rivers draining land, of which the contiguity is indicated by the occasional presence of terrestrial and freshwater shells.

Fossil quadrumana. — Until within a few years (1836, 1837), not a single bone of any quadrumanous animal, such as the orang, ape, baboon, and monkey, had been discovered in a fossil state, although so much progress had been made in bringing to light the extinct mammalia of successive tertiary eras, both carnivorous and herbivorous. The total absence of these anthropomorphous tribes among the records of a former world, had led some to believe that the type of organization most nearly resembling the human, came so late in the order of creation, as to be scarcely, if at all, anterior to that of man. That such generalizations were premature, I endeavoured to point out in former editions of this work *, in which I stated that the bones of quadrupeds hitherto met with in tertiary deposits, were chiefly those which frequent marshes, rivers, or the borders of lakes, as the elephant, rhinoceros, hippopotamus, tapir, hog, deer, and ox, while species which live in trees are extremely rare in a fossil state. I also affirmed, that we had as yet no

* See Principles of Geology, 1st ed. 1830, vol. i. p. 152., and subsequent editions.

data for determining how great a number of the one kind we ought to find before we have a right to expect a single individual of the other. Lastly, I observed that the climate of the more modern (or Post-Eocene) tertiary periods in England was not tropical, and that in regard to the London clay, of which the crocodiles, turtles, and fossil fruits, implied a climate hot enough for the quadrumana, we had as yet made too little progress in ascertaining what were the Eocene pachydermata of England, to entitle us to expect to have discovered any quadrumana of the same date.

Since those remarks were first written, in 1829, a great number of extinct species have been added to our collections of tertiary mammalia, from Great Britain and other parts of the world. At length, between the years 1836 and 1839, a few remains of quadrumana were found in France and England, India and Brazil. Those of India, belonging to more than one extinct species of monkey, were first discovered near Saharunpore, in lat. 30° N., in tertiary strata, of which the age is not yet determined; the Brazilian fossil, brought from the basin of the Rio das Velhas, about lat. 18° S., is referable to a form now peculiar to America, allied to the genus Callithrix, the species being extinct. The skull and other bones met with in the South of France, belong to a gibbon, or one of the tailless apes, which stand next in the scale of organization to the orang. It occurred at Sansan, about forty miles west of Toulouse, in lat. 43° 40′ N., in freshwater strata, probably of the Miocene or middle tertiary period. Lastly, the English quadrumane occurred in a more ancient stratum than the rest, and at a point more remote from the equator. It belongs to the genus Macacus, is an extinct species,

and was found in Suffolk, in lat. 52° *, in the London clay, the fossils of which, such as crocodiles, turtles, shells of the genus nautilus, and many curious fruits, had already led geologists to the conclusion that the climate of that era (the Eocene) was warm and nearly tropical.

The result then, of our inquiry into the evidence of the successive development of the animal and vegetable kingdoms, may be stated in a few words. In regard to *plants*, if we neglect the obscure and ambiguous impressions found in some of the oldest

* The first quadrumanous fossils discovered in India were observed in 1836 in the Sewalik Hills, a lower range of the Himalayan Mountains, by Lieutenants Baker and Durand, by whom their osteological characters were determined (Journ. of Asiat. Soc. of Bengal, vol. v. p. 739.), and in the year following, other fossils of the same class were brought to light and described by Capt. Cautley and Dr. Falconer. These were imbedded, like the former, in tertiary strata of conglomerate, sand, marl, and clay, in the Sub-Himalayan Mountains. (Ibid. vol. v. p. 379. Nov. 1836, and vol. vi. p. 354. May, 1837.)

The Brazilian quadrumane was found, with a great many other extinct species of animals, by a Danish naturalist, Dr. Lund, between the rivers Francisco and Velhas, tributaries of the Parana, in 1837.

The gibbon of the South of France was found by M. Lartet in the beginning of 1837, and determined by M. de Blainville. It occurred near Auch, in the department of Gers, about forty miles west of Toulouse, in freshwater marl, limestone, and sand. They were accompanied by the remains of the mastodon, dinotherium, palæotherium, rhinoceros, gigantic sloth, and other extinct quadrupeds. (Bulletin de la Soc. Géol. de France, tom. viii. p. 92.)

The British quadrumane was discovered in 1839, by Messrs. William Colchester and Searles Wood, at Kyson, near Woodbridge, in Suffolk, and was referred by Professor Owen to the genus Macacus. (Mag. of Nat. Hist. Sept. 1839. Taylor's Annals of Nat. Hist., No. xxiii. Nov. 1839.)

fossiliferous rocks, which can lead to no safe conclusions, we may consider those which characterize the great carboniferous group as the first deserving particular attention. They are by no means confined to the simplest forms of vegetation, as to the cryptogamia; but, on the contrary, belong to all the leading divisions of the vegetable kingdom; some of the more fully developed forms, both of dicotyledons and monocotyledons, having already been discovered, even among the first three or four hundred species brought to light: it is therefore superfluous to pursue this part of the argument farther.

If we then examine the animal remains of the oldest formations, we find bones and skeletons of fish in the old red sandstones, and even in some transition or primary fossiliferous limestones below it; in other words, we have already vertebrated animals in the most ancient strata, respecting the fossils of which we can be said to possess extensive information.

In regard to birds and quadrupeds, their remains are usually wanting in *marine* deposits of every era, even where interposed freshwater strata contain those fossils in abundance, as in the Paris basin. The secondary strata of Europe are for the most part marine, and there is as yet only one instance of the occurrence of mammiferous fossils in them, individuals of two distinct genera having been found in the slate of Stonesfield, a rock unquestionably of the Oolitic period, and which appears, from several other circumstances, to have been formed near the point where some river entered the sea.

When we examine the tertiary groups, we find in the Eocene or oldest strata of that class the remains of a great assemblage of the highest or mammiferous order,

all of extinct species, and in the Miocene beds, or those of a newer tertiary epoch, other forms, for the most part of lost species, and almost entirely distinct from the Eocene tribes. Another change is again perceived, when we investigate the fossils of still later periods. But in this succession of quadrupeds, we cannot detect any signs of a progressive development of organization,— any clear indication that the Eocene fauna was less perfect than the Miocene, or the Miocene than that of the Older or Newer Pliocene periods.

Recent origin of man.—If, then, the popular theory of the successive development of the animal and vegetable world, from the simplest to the most perfect forms, rests on a very insecure foundation; it may be asked, whether the recent origin of man lends any support to the same doctrine, or how far the influence of man may be considered as such a deviation from the analogy of the order of things previously established, as to weaken our confidence in the uniformity of the course of nature.

I need not dwell on the proofs of the low antiquity of our species, for it is not controverted by any experienced geologist; indeed the real difficulty consists in tracing back the signs of man's existence on the earth to that comparatively modern period when species, now his contemporaries, began greatly to predominate. If there be a difference of opinion respecting the occurrence in certain deposits of the remains of man and his works, it is always in reference to strata confessedly of the most modern order; and it is never pretended that our race co-existed with assemblages of animals and plants, of which *all or even a large proportion of the species* are extinct. From the concurrent testimony of history and tradition, we learn that

parts of Europe, now the most fertile and most completely subjected to the dominion of man, were, less than three thousand years ago, covered with forests, and the abode of wild beasts. The archives of nature are in perfect accordance with historical records; and when we lay open the most superficial covering of peat, we sometimes find therein the canoes of the savage, together with huge antlers of the wild stag, or horns of the wild bull. In caves now open to the day in various parts of Europe, the bones of large beasts of prey occur in abundance; and they indicate that, at periods comparatively modern in the history of the globe, the ascendancy of man, if he existed at all, had scarcely been felt by the brutes.*

No inhabitant of the land exposes himself to so many dangers on the waters as man, whether in a savage or a civilized state†; and there is no animal, therefore, whose skeleton is so liable to become imbedded in lacustrine or submarine deposits: nor can it be said that his remains are more perishable than those of other animals; for in ancient fields of battle, as Cuvier has observed, the bones of men have suffered as little decomposition as those of horses which were buried in the same grave.‡ But even if the more solid parts of our species had disappeared, the impression of their form would have remained engraven on the rocks, as have the traces of the tenderest leaves of plants, and the soft integuments of many animals. Works of art, moreover, composed of the most inde-

* Respecting the probable antiquity assignable to certain human bones and works of art found intermixed with remains of extinct animals in several caves in France, see Book iii. ch. xiv.

† See Book iii. ch. xvi. ‡ Ibid.

structible materials, would have outlasted almost all the organic contents of sedimentary rocks. Edifices, and even entire cities, have, within the times of history, been buried under volcanic ejections, submerged beneath the sea, or engulphed by earthquakes; and had these catastrophes been repeated throughout an indefinite lapse of ages, the high antiquity of man would have been inscribed in far more legible characters on the framework of the globe than are the forms of the ancient vegetation which once covered the islands of the northern ocean, or of those gigantic reptiles which at still later periods peopled the seas and rivers of the northern hemisphere.*

Dr. Prichard has argued that the human race have not always existed on the surface of the earth, because "the strata of which our continents are composed were once a part of the ocean's bed" — "mankind had a beginning, since we can look back to the period when the surface on which they lived began to exist."† This proof, however, is insufficient, for many thousands of human beings now dwell in various quarters of the globe where marine species lived within the times of history, and, on the other hand, the sea now prevails permanently over large districts once inhabited by thousands of human beings. Nor can this interchange of sea and land ever cease while the present causes are in existence. It is conceivable, therefore, that terrestrial species might be older than the continents which they inhabit, and aquatic species of higher antiquity than the lakes and seas which they people.

Doctrine of successive development not confirmed by the admission that man is of modern origin. — It is on

* See Book III. ch. xvi.

† Phys. Hist. of Mankind, vol. ii. p. 594.

other grounds that we are entitled to infer that man is, comparatively speaking, of modern origin; and if this be assumed, we may then ask whether his introduction can be considered as one step in a progressive system, by which, as some suppose, the organic world advanced slowly from a more simple to a more perfect state? In reply to this question, it should first be observed, that the superiority of man depends not on those faculties and attributes which he shares in common with the inferior animals, but on his reason, by which he is distinguished from them. When it is said that the human race is of far higher dignity than were any pre-existing beings on the earth, it is the intellectual and moral attributes only of our race, not the animal, which are considered; and it is by no means clear, that the organization of man is such as would confer a decided pre-eminence upon him, if, in place of his reasoning powers, he was merely provided with such instincts as are possessed by the lower animals.

If this be admitted, it would by no means follow, even if there had been sufficient geological evidence in favour of the theory of progressive development, that the creation of man was the last link in the same chain. For the sudden passage from an irrational to a rational animal is a phenomenon of a distinct kind from the passage from the more simple to the more perfect forms of animal organization and instinct. To pretend that such a step, or rather leap, can be part of a regular series of changes in the animal world, is to strain analogy beyond all reasonable bounds.

Introduction of man, to what extent a change in the system.—But setting aside the question of progressive development, another and a far more difficult one may arise out of the admission that man is comparatively of

modern origin. Is not the interference of the human species, it may be asked, such a deviation from the antecedent course of physical events, that the knowledge of such a fact tends to destroy all our confidence in the uniformity of the order of nature, both in regard to time past and future? If such an innovation could take place after the earth had been exclusively inhabited for thousands of ages by inferior animals, why should not other changes as extraordinary and unprecedented happen from time to time? If one new cause was permitted to supervene, differing in kind and energy from any before in operation, why may not others have come into action at different epochs? Or what security have we that they may not arise hereafter? And if such be the case, how can the experience of one period, even though we are acquainted with all the possible effects of the then existing causes, be a standard to which we can refer all natural phenomena of other periods?

Now these objections would be unanswerable, if adduced against one who was contending for the absolute uniformity throughout all time of the succession of sublunary events—if, for example, he was disposed to indulge in the philosophical reveries of some Egyptian and Greek sects, who represented all the changes both of the moral and material world as repeated at distant intervals, so as to follow each other in their former connexion of place and time. For they compared the course of events on our globe to astronomical cycles; and not only did they consider all sublunary affairs to be under the influence of the celestial bodies, but they taught that on the earth, as well as in the heavens, the same identical phenomena recurred again and again in a perpetual vicissitude.

The same individual men were doomed to be re-born, and to perform the same actions as before; the same arts were to be invented, and the same cities built and destroyed. The Argonautic expedition was destined to sail again with the same heroes, and Achilles with his Myrmidons to renew the combat before the walls of Troy.

> Alter erit tum Tiphys, et altera quæ vehat Argo
> Dilectos heroas: erunt etiam altera bella,
> Atque iterum ad Trojam magnus mittetur Achilles.*

The geologist, however, may condemn these tenets as absurd, without running into the opposite extreme, and denying that the order of nature has, from the earliest periods, been uniform in the same sense in which we believe it to be uniform at present, and expect it to remain so in future. We have no reason to suppose, that when man first became master of a small part of the globe, a greater change took place in its physical condition than is now experienced when districts, never before inhabited, become successively occupied by new settlers. When a powerful European colony lands on the shores of Australia, and introduces at once those arts which it has required many centuries to mature; when it imports a multitude of plants and large animals from the opposite extremity of the earth, and begins rapidly to extirpate many of the indigenous species, a mightier revolution is effected in a brief period than the first entrance of a savage horde, or their continued occupation of the country for many

* Virgil, Eclog. iv. For an account of these doctrines, see Dugald Stewart's Elements of the Philosophy of the Human Mind, vol. ii. chap. ii. sect. 4., and Prichard's Egypt. Mythol. 177.

centuries, can possibly be imagined to have produced. If there be no impropriety in assuming that the system is uniform when disturbances so unprecedented occur in certain localities, we can with much greater confidence apply the same language to those primeval ages when the aggregate number and power of the human race, or the rate of their advancement in civilization, must be supposed to have been far inferior. In reasoning on the state of the globe immediately before our species was called into existence, we must be guided by the same rules of induction as when we speculate on the state of America in the interval that elapsed between the introduction of man into Asia, the supposed cradle of our race, and the arrival of the first adventurers on the shores of the New World. In that interval, we imagine the state of things to have gone on according to the order now observed in regions unoccupied by man. Even now, the waters of lakes, seas, and the great ocean, which teem with life, may be said to have no immediate relation to the human race — to be portions of the terrestrial system of which man has never taken, nor ever can take, possession; so that the greater part of the inhabited surface of the planet may remain still as insensible to our presence as before any isle or continent was appointed to be our residence.

If the barren soil around Sydney had at once become fertile upon the landing of our first settlers; if, like the happy isles whereof the poets have given us such glowing descriptions, those sandy tracts had begun to yield spontaneously an annual supply of grain, we might then, indeed, have fancied alterations still more remarkable in the economy of nature to have attended the first coming of our species into the planet. Or if,

when a volcanic island like Ischia was, for the first time, brought under cultivation by the enterprise and industry of a Greek colony, the internal fire had become dormant, and the earthquake had remitted its destructive violence, there would then have been some ground for speculating on the debilitation of the subterranean forces, when the earth was first placed under the dominion of man. But after a long interval of rest, the volcano bursts forth again with renewed energy, annihilates one half of the inhabitants, and compels the remainder to emigrate. The course of nature remains evidently unchanged; and, in like manner, we may suppose the general condition of the globe, immediately before and after the period when our species first began to exist, to have been the same, with the exception only of man's presence.

The modifications in the system of which man is the instrument, do not, perhaps, constitute so great a deviation from previous analogy as we usually imagine; we often, for example, form an exaggerated estimate of the extent of our power in extirpating some of the inferior animals, and causing others to multiply; a power which is circumscribed within certain limits, and which, in all likelihood, is by no means exclusively exerted by our species.* The growth of human population cannot take place without diminishing the numbers, or causing the entire destruction, of many animals. The larger beasts of prey in particular give way before us, but other quadrupeds of smaller size, and innumerable birds, insects, and plants, which are inimical to our interests, increase in spite of us, some attacking our food, others our raiment and persons,

* See Book III. ch. ix.

and others interfering with our agricultural and horticultural labours. We behold the rich harvest which we have raised with the sweat of our brow devoured by myriads of insects, and are often as incapable of arresting their depredations, as of staying the shock of an earthquake, or the course of a stream of lava.

A great philosopher has observed, that we can command nature only by obeying her laws; and this principle is true even in regard to the astonishing changes which are superinduced in the qualities of certain animals and plants by domestication and garden culture. I shall point out in the third book that we can only effect such surprising alterations by assisting the development of certain instincts, or by availing ourselves of that mysterious law of their organization, by which individual peculiarities are transmissible from one generation to another.*

It is probable from these and many other considerations, that as we enlarge our knowledge of the system, we shall become more and more convinced, that the alterations caused by the interference of man deviate far less from the analogy of those effected by other animals than is usually supposed.† We are often misled, when we institute such comparisons, by our knowledge of the wide distinction between the instincts of animals and the reasoning power of man; and we are apt hastily to infer, that the effects of a rational and an irrational species, considered merely *as physical agents*, will differ almost as much as the faculties by which their actions are directed.

It is not, however, intended that a real departure from the antecedent course of physical events cannot

* See Book III. ch. iii. † Id. chapters v. vi. vii. and ix.

be traced in the introduction of man. If that latitude of action which enables the brutes to accommodate themselves in some measure to accidental circumstances, could be imagined to have been at any former period so great, that the operations of instinct were as much diversified as are those of human reason, it might, perhaps, be contended, that the agency of man did not constitute an anomalous deviation from the previously established order of things. It might then have been said, that the earth's becoming at a particular period the residence of human beings, was an era in the moral, not in the physical world — that our study and contemplation of the earth, and the laws which govern its animate productions, ought no more to be considered in the light of a disturbance or deviation from the system, than the discovery of the satellites of Jupiter should be regarded as a physical event affecting those heavenly bodies. Their influence in advancing the progress of science among men, and in aiding navigation and commerce, was accompanied by no reciprocal action of the human mind upon the economy of nature in those distant planets; and so the earth might be conceived to have become, at a certain period, a place of moral discipline, and intellectual improvement to man, without the slightest derangement of a previously existing order of change in its animate and inanimate productions.

The distinctness, however, of the human from all other species, considered merely as an efficient cause in the physical world, is real; for we stand in a relation to contemporary species of animals and plants widely different from that which other irrational animals can ever be supposed to have held to each other. To modify their instincts, relative numbers, and geo-

graphical distribution, in a manner superior in degree, and in some respects very different in kind, from that in which any other species can affect the rest. Besides, the progressive movement of each successive generation of men causes the human species to differ more from itself in power at two distant periods, than any one species of the higher order of animals differs from another. The establishment, therefore, by geological evidence, of the first intervention of such a peculiar and unprecedented agency, long after other parts of the animate and inanimate world existed, affords ground for concluding that the experience during thousands of ages of all the events which may happen on this globe would not enable a philosopher to speculate with confidence concerning future contingencies.

If, then, an intelligent being, after observing the order of events for an indefinite series of ages, had witnessed at last so wonderful an innovation as this, to what extent would his belief in the regularity of the system be weakened? — would he cease to assume that there was permanency in the laws of nature? — would he no longer be guided in his speculations by the strictest rules of induction? To these questions it may be answered, that, had he previously presumed to dogmatize respecting the absolute uniformity of the order of nature, he would undoubtedly be checked by witnessing this new and unexpected event, and would form a more just estimate of the limited range of his own knowledge, and the unbounded extent of the scheme of the universe. But he would soon perceive that no one of the fixed and constant laws of the animate or inanimate world was subverted by human agency, and that the modifications now introduced for the first

time were the accompaniments of new and extraordinary circumstances, and those not of a *physical* but a *moral* nature. The deviation permitted would also appear to be as slight as was consistent with the accomplishment of the new *moral* ends proposed, and to be in a great degree temporary in its nature, so that, whenever the power of the new agent was withheld, even for a brief period, a relapse would take place to the ancient state of things; the domesticated animal, for example, recovering in a few generations its wild instinct, and the garden-flower and fruit-tree reverting to the likeness of the parent stock.

Now, if it would be reasonable to draw such inferences with respect to the future, we cannot but apply the same rules of induction to the past. We have no right to anticipate any modifications in the results of existing causes in time to come, which are not conformable to analogy, unless they be produced by the progressive development of human power, or perhaps by some other new relations which may hereafter spring up between the moral and material worlds. In the same manner, when we speculate on the vicissitudes of the animate and inanimate creation in former ages, we ought not to look for any anomalous results, unless where man has interfered, or unless clear indications appear of some other *moral* source of temporary derangement.

CHAPTER X.

SUPPOSED INTENSITY OF AQUEOUS AND IGNEOUS FORCES AT REMOTE PERIODS.

Intensity of aqueous causes — Slow accumulation of strata proved by fossils — Rate of denudation can only keep pace with deposition — Erratics, and effects of ice — Deluges and the causes to which they are referred — Supposed universality of ancient deposits — Former intensity of igneous action — Volcanic formations of all geological periods — Plutonic rocks of different ages — Gradual development of subterranean movements — Faults.

Intensity of aqueous causes. — The great problem considered in the preceding chapters, namely, whether the former changes of the earth made known to us by geology, resemble in kind and degree those now in daily progress, may still be contemplated from several other points of view. We may inquire, for example, whether there are any grounds for the belief entertained by many, that the intensity both of aqueous and of igneous forces, in remote ages, far exceeded that which we witness in our own times.

First, then, as to aqueous causes; it has been shown in our history of the science, that Woodward did not hesitate, in 1695, to teach that the entire mass of fossiliferous strata contained in the earth's crust, had been deposited in a few months; and, consequently, as their mechanical and derivative origin was already admitted, the reduction of rocky masses into mud, sand,

and pebbles, the transportation of the same to a distance, and their accumulation elsewhere in regular strata, were all assumed to have taken place with a rapidity unparalleled in modern times. This doctrine was modified by degrees, in proportion as different classes of organic remains, such as shells, corals, and fossil plants, had been studied with attention. Analogy led every naturalist to assume that each full-grown individual of the animal or vegetable kingdom, had required a certain number of months or years for the attainment of maturity, and the perpetuation of its species by generation; and thus the first approach was made to the conception of a common standard of time, without which there are no means whatever of measuring the comparative rate at which any succession of events has taken place at two distinct periods. This standard consisted of the average duration of the lives of individuals of the same genera or families in the animal and vegetable kingdoms; and the multitude of fossils dispersed through successive strata, implied the continuance of the same species for many generations. At length the idea that species themselves had had a limited duration, arose out of the observed fact that sets of strata of different ages contained fossils of distinct species. Finally, the opinion became general, that in the course of ages, one assemblage of animals and plants had again and again disappeared, and new tribes had started into life to replace them.

Denudation.— In addition to the proofs derived from organic remains, the forms of stratification led, also, on a full investigation, to the belief that sedimentary rocks had been slowly deposited; but it was still supposed that *denudation*, or the power of running water, and the waves and currents of the ocean, to strip

off superior strata, and lay bare the rocks below, had formerly operated with a rapidity unparalleled in our own times. These opinions were both illogical and inconsistent, because deposition and denudation are parts of the same process, and what is true of the one must be true of the other. Their speed must be always limited by the same causes, and the conveyance of solid matter to a particular region can only keep pace with its removal from another, so that the aggregate of sedimentary strata in the earth's crust can never exceed in volume the amount of solid matter which has been ground down and washed away by running water. How vast then must be the spaces which this abstraction of matter has left vacant! how far exceeding in dimensions all the valleys, however numerous, and the hollows, however vast, which we can prove to have been cleared out by aqueous erosion! The evidences of the work of denudation are defective, because it is the nature of every destroying cause to obliterate the signs of its own agency; but the amount of reproduction in the form of sedimentary strata must always afford a true measure of the denudation which the earth's surface has undergone.

Erratics. — The next phenomenon to which advocates of the excessive power of running water in times past have appealed, is the enormous size of the blocks called *erratic*, which lie scattered over the northern parts of Europe and North America. Unquestionably a large proportion of these blocks have been transported far from their original position, for between them and the parent rocks we now find, not unfrequently, deep seas and valleys intervening, or hills more than a thousand feet high. To explain the present situation of such travelled fragments, a deluge

of mud has been imagined by some to have come from the north, bearing along with it sand, gravel, and stony fragments, some of them hundreds of tons in weight. This flood, in its transient passage over the continents, dispersed the boulders irregularly over hill, valley, and plain, or forced them along over a surface of hard rock, so as to polish it and leave it indented with parallel scratches and grooves, — such markings as are still visible in the rocks of Scandinavia, Scotland, Canada, and many other countries.

There can be no doubt that the myriads of angular and rounded blocks above alluded to cannot have been borne along by ordinary rivers or marine currents, so great is their volume and weight, and so clear are the signs, in many places, of time having been occupied in their successive deposition; for they are often distributed at various depths through heaps of regularly stratified sand and gravel. No waves of the sea raised by earthquakes, nor the bursting of lakes dammed up for a time by landslips or by avalanches of snow, can account for the observed facts; but I shall endeavour to show, in the third chapter of the next book, that a combination of existing causes may have conveyed erratics into their present situations.

The causes which will be referred to are, first, the carrying power of ice; secondly, that of running water; thirdly, the upward movement of the bed of the sea, converting it gradually into land. Without entering at present into any details respecting these causes, I may mention that the transportation of blocks by ice is now simultaneously in progress in the cold and temperate latitudes, both of the northern and southern hemisphere, as, for example,

on the coasts of Canada and Gulf of St. Lawrence, and also in South Georgia, Patagonia, and Chili. In those regions the uneven bed of the ocean is becoming strewed over with ice-drifted fragments, which have either stranded on shoals, or been dropped in deep water by melting bergs. The entanglement of boulders in drift ice will also be shown to occur annually in North America, and these stones, when firmly frozen into ice, wander year after year from Labrador to the St. Lawrence, and reach points of the western hemisphere farther south than any part of Great Britain.

The general absence of erratics in the warmer parts of the equatorial regions of Asia, Africa, and America, confirms the same views. As to the polishing and grooving of hard rocks, it has lately been ascertained that glaciers give rise to these effects when pushing forward sand, pebbles, and rocky fragments, and causing them to grate along the bottom. Nor can there be any doubt that icebergs, when they run aground on the floor of the ocean, imprint similar marks upon it.

It is unnecessary, therefore, to refer to deluges, or even to speculate on the former existence of a climate more severe than that now prevailing in the western hemisphere, to explain the geographical distribution of most of the European erratics.

Deluges.—As deluges have been often alluded to, I shall say something of the causes which may be supposed to give rise to these grand movements of water. Geologists who believe that mountain-chains have been thrown up suddenly at many successive epochs, imagine that the waters of the ocean may be raised by these convulsions, and then break in terrific waves upon the land, sweeping over whole continents, hollow-

ing out valleys, and transporting sand, gravel, and erratics, to great distances. The sudden rise of the Alps or Andes, it is said, may have produced a flood even subsequently to the time when the earth became the residence of man. But it seems strange that none of the writers who have indulged their imaginations in conjectures of this kind, should have ascribed a deluge to the sudden conversion of part of the unfathomable ocean into a shoal rather than to the rise of mountain-chains. In the latter case, the mountains themselves could do no more than displace a certain quantity of atmospheric air, whereas, the instantaneous formation of the shoal would displace a vast body of water, which being heaved up to a great height might roll over and permanently submerge a large portion of a continent.

If we restrict ourselves to combinations of causes at present known, it would seem that the two principal sources of extraordinary inundations are, first, the escape of the waters of a large lake raised far above the sea; and, secondly, the pouring down of a marine current into lands depressed below the mean level of the ocean.

As an example of the first of these cases, we may take Lake Superior, which is more than 400 geographical miles in length and about 150 in breadth, having an average depth of from 500 to 900 feet. This vast body of freshwater is raised no less than 600 feet above the level of the ocean; and the lowest part of the barrier which separates the south-western boundary of the lake from those streams which flow into the head waters of the Mississippi is not more than 600 feet high. If, therefore, a series of partial subsidences should lower the barrier 600 feet, any subsequent

rending or depression, even of a few yards at a time, would allow the sudden escape of vast floods of water into a hydrographical basin of enormous extent. If the event happened in the dry season, when the ordinary channels of the Mississippi and its tributaries are in a great degree empty, the inundation might not be considerable, but if in the flood-season, a region capable of supporting a population of many millions might be suddenly submerged. But even this event would be insufficient to cause a violent rush of water, and to produce those effects usually called diluvial, for the difference of level between Lake Superior and the Gulf of Mexico is no more than 600 feet in a distance of 1800 miles. Nor would it be consistent with analogy to calculate on the entire removal of the barrier at once. We ought rather to expect it to sink by a series of successive subsidences, or to be fissured again and again, and the channel of discharge to be widened and deepened gradually as the rushing waters escape.

The second case before adverted to is where there are large tracts of dry land beneath the mean level of the ocean. It seems, after much controversy, to be at length a settled point, that the Caspian is really 108 feet lower than the Black Sea. As the Caspian covers an area about equal to that of Spain, and as its shores are in general low and flat, there must be many thousand square miles of country less than 108 feet above the level of that inland sea, and consequently depressed below the Black Sea and Mediterranean. This area includes the site of the populous city of Astrakhan and other towns. Into this region the ocean would pour its waters, if the land now intervening between the Sea of Azof and the Caspian should subside. Yet, even

if this event should occur, it is most probable that the submergence of the whole region would not be accomplished simultaneously, but by a series of minor floods, the sinking of the barrier being gradual.*

Supposed universality of ancient deposits.— The next fallacy which has helped to perpetuate the doctrine that the operations of water were on a grander scale in ancient times, is founded on the indefinite areas

* It has been suspected ever since the middle of the last century, that the Caspian was lower than the ocean, it being known that in Astrakhan the mercury in the barometer generally stands above thirty inches. In 1811, MM. Engelhardt and Parrot attempted to determine the exact amount of difference by a series of levellings and barometrical measurements across the isthmus at two different places near the foot of Mount Caucasus. The result of their operations led them to the opinion that the Caspian was more than 300 feet below the Black Sea. But the correctness of the observations having afterwards been called in question, M. Parrot revisited the ground in 1829 and 1830, and inferred from new levellings, that the mouth of the Don was between three and four feet lower than that of the Wolga; in other words, that the sea of Azof which communicates with the Black Sea was actually lower than the Caspian! Other statements, no less contradictory, having been made by other observers, the Russian government at length directed the Academy of St. Petersburg, to send an expedition in 1836, to decide the point by a trigonometrical survey, from which it appeared that the Caspian is 101 Russian, or 108 English feet lower than the Black Sea. (For authorities see Journ. Roy. Geograph. Soc. vol. viii. p. 135.)

According to the researches of Mr. G. Moore and Mr. Beek made in 1837, the level of the Dead Sea was estimated by the temperature of boiling water to be 500 feet below the level of the Mediterranean, a result confirmed by the barometrical experiments of Professor Schubert of Munich, according to which the difference of level is 598 feet. The last-mentioned traveller also states, that the Lake of Tiberias is 500 feet below the Mediterranean. (Journ. Roy. Geograph. Soc. vol. viii. p. 250.)

over which homogeneous deposits were supposed to extend. No modern sedimentary strata, it is said, equally identical in mineral character and fossil contents, can be traced continuously from one quarter of the globe to another. But the first propagators of these opinions were very slightly acquainted with the inconstancy in mineral composition of the ancient formations, and equally so of the wide spaces over which the same kind of sediment is now actually distributed by rivers and currents in the course of centuries. The persistency of character in the older series was exaggerated, its extreme variability in the newer was assumed without proof. In the chapter which treats of river-deltas and the dispersion of sediment by currents, and in the description of reefs of coral now growing over areas many hundred miles in length, I shall have opportunities of convincing the reader of the danger of hasty generalizations on this head.

In regard to the imagined universality of particular rocks of ancient date, it was almost unavoidable that this notion, when once embraced, should be perpetuated; for the same kinds of rock have occasionally been reproduced at successive epochs: and when once the agreement or disagreement in mineral character alone was relied on as the test of age, it followed that similar rocks, if found even at the antipodes, were referred to the same era, until the contrary could be shown.

Now it is usually impossible to combat such an assumption on geological grounds, so long as we are imperfectly acquainted with the order of superposition and the organic remains of these same formations. Thus, for example, a group of red marl and red sandstone, containing salt and gypsum, being interposed in

England between the Lias and the Coal, all other red marls and sandstones, associated some of them with salt, and others with gypsum, and occurring not only in different parts of Europe, but in Peru, India, the salt deserts of Asia, those of Africa — in a word, in every quarter of the globe, were referred to one and the same period. The burden of proof was not supposed to rest with those who insisted on the identity in age of all these groups — their identity in mineral composition was thought sufficient. It was in vain to urge as an objection the improbability of the hypothesis which implies that all the moving waters on the globe were once simultaneously charged with sediment of a red colour.

But the rashness of pretending to identify, in age, all the red sandstones and marls in question, has at length been sufficiently exposed, by the discovery that, even in Europe, they belong decidedly to many different epochs. It is already ascertained, that the red sandstone and red marl containing the rock-salt of Cardona in Catalonia, may be referred to the period of our Chalk and Green Sand. It is also known that certain red marls and variegated sandstones, in Auvergne, which are undistinguishable in mineral composition from the New Red Sandstone of English geologists, belong, nevertheless, to the Eocene period: and, lastly, the gypseous red marl of Aix, in Provence, formerly supposed to be a marine secondary group, is now acknowledged to be a tertiary freshwater formation.

Nor was the nomenclature commonly adopted in geology without its influence in perpetuating the erroneous doctrine of universal formations. Such names for example, as Chalk, Green Sand, Oolite, Red Marl, and others, were given to some of the principal

fossiliferous groups in consequence of mineral peculiarities which happened to characterize them in the countries where they were first studied. When geologists had at length shown, by means of fossils and the order of superposition, that other strata, entirely dissimilar in colour, texture, and composition, were of contemporaneous date, it was thought convenient still to retain the old names. That these were often inappropriate was admitted, but the student was taught to understand them in no other than a chronological sense, so that the Chalk might not be a white cretaceous rock, but a hard dolomitic limestone, as in the Pyrenees, or a black slate, as at Glaris and the Lake of Thun, in Switzerland. In like manner the Green Sand, it was said, might in some places be represented by red sandstone, red marl, salt, and gypsum, as in the north of Spain. So the oolitic texture was declared to be rather an exception than otherwise to the general rule in rocks of the Oolitic period; and it often became necessary to affirm that no particle of carbonaceous matter could be detected in districts where the true Coal series abounded. In spite of every precaution the habitual use of this language could scarcely fail to instil into the mind of the pupil an idea that chalk, coal, salt, red marl, or the oolitic structure were far more widely characteristic of the rocks of a given age than was really the case.

There is still another cause of deception disposing us to ascribe a more limited range to the newer sedimentary formations as compared to the older, namely, the very general concealment of the newer strata beneath the waters of lakes and seas, and the wide exposure above water of the more ancient. The Chalk, for example, now seen stretching for thousands of

miles over different parts of Europe has become visible to us by the effect, not of one, but of many distinct series of subterranean movements. Time has been required, and a succession of geological periods, to raise it above the waves in so many regions; and if calcareous rocks of the Eocene or Miocene periods have been formed, as homogeneous in mineral composition throughout equally extensive regions, it may require convulsions as numerous as all those which have occurred since the origin of the Chalk to bring them up within the sphere of human observation. Hence the rocks of more modern periods may appear partial, as compared to those of remoter eras, not because of any original inferiority in their extent, but because there has not been sufficient time since their origin for the development of a great series of elevatory movements.

In regard, however, to one of the most important characteristics of sedimentary rocks, their organic remains, many naturalists of high authority suspect that the same species of fossils are more uniformly distributed through formations of high antiquity than in those of more modern date, and that distinct zoological and botanical provinces, as they are called, which form so striking a feature in the living creation, were not established at remote eras. Thus the plants of the Coal, the shells and trilobites of the Silurian rocks, and the ammonites of the Oolite, have been supposed to have a wider geographical range than any living species of trees, crustaceans, or mollusks.

It seems by no means unlikely that this opinion will prove, to a certain extent, well founded, but no comparison has yet been made of a large assemblage of ...sils from two very distant points with sufficient

minuteness to entitle us to pronounce on the specific identity of the whole. In the theory of climate proposed in the seventh and eighth chapters, we have seen how the altered position of sea and land might render the temperature of the globe more uniform, in which case the fauna and flora of the earth would be less diversified than now.

Supposed former intensity of igneous action.—In reasoning on the igneous as well as the aqueous forces, geologists have been fain to represent nature at remote epochs as having been prodigal of violence and parsimonious of time. Now although it is less easy to determine the relative ages of the volcanic than of the fossiliferous formations, it is undeniable that igneous rocks have been produced at all geological periods, or as often as we find distinct deposits marked by peculiar animal and vegetable remains. It can be shown that rocks commonly called trappean have been injected into fissures, and ejected at the surface, both before and during the deposition of the Carboniferous series, and at the time when the Magnesian Limestone, and when the Upper New Red Sandstone were formed, or when the Lias, Oolite, Green Sand, Chalk, and the several tertiary groups newer than the Chalk, originated in succession. Nor is this all; distinct volcanic products may be referred to the subordinate divisions of each period, such as the Carboniferous, as in the county of Fife, in Scotland, where certain masses of contemporaneous trap are associated with the Lower, others with the Upper Coal-measures. And if one of these masses is more minutely examined, we find it to consist of the products of a great many successive outbursts, by which scoriæ and lava were again and again emitted, and afterwards consolidated, then fissured, and

finally traversed by melted matter constituting what are called dikes. As we enlarge, therefore, our knowledge of the ancient rocks formed by subterranean heat, we find ourselves compelled to regard them as the aggregate effects of innumerable eruptions, each of which may have been comparable in violence to those now experienced in volcanic regions.

It may indeed be said that we have as yet no data for estimating the relative volume of matter simultaneously in a state of fusion at two given periods, as if we were to compare the columnar basalt of Staffa and its environs with the lava poured out in Iceland in 1783; but for this very reason it would be rash and unphilosophical to assume an excess of ancient as contrasted with modern outpourings of melted matter at particular periods of time.* It would be still more presumptuous to take for granted that the more deep-seated effects of subterranean heat surpassed at remote eras the corresponding effects of internal heat in our own times. Certain porphyries and granites, and all the rocks commonly called plutonic, are now generally supposed to have resulted from the slow cooling of materials fused and solidified under great pressure; and we cannot doubt that beneath existing volcanos there are large spaces filled with melted stone, which must for centuries remain in an incandescent state, and then cool and become hard and crystalline when the subterranean heat shall be exhausted. That lakes of lava are continuous for hundreds of miles beneath the Chilian Andes, seems established by observations made in the year 1835.

Now, wherever the fluid contents of such reservoirs

* See Vol. II. p. 258.

are poured out successively from craters in the open air or at the bottom of the sea, the matter so ejected may afford evidence by its arrangement of having originated at different periods; but if the subterranean residue after the withdrawal of the heat be converted into crystalline or plutonic rock, the entire mass will seem to have been formed at once, however countless the ages required for its fusion and subsequent refrigeration. As the idea that all the granite in the earth's crust was produced simultaneously, and in a primitive state of the planet, has now been universally abandoned; so the suggestion above adverted to may put us on our guard against too readily adopting another opinion, namely, that each large mass of granite was generated in a brief period of time.

The doctrine of some modern writers of authority that crystalline rocks, such as granite, gneiss, mica-schist, quartzite, and others, were produced in the greatest abundance in the earlier ages of the planet, and that their formation has ceased altogether in our own times, will be controverted in the thirteenth chapter.

Gradual development of subterranean movements.— The extreme violence of the subterranean forces in remote ages has been often inferred from the fact that the older rocks are more fractured and dislocated than the newer. But what other result could we have anticipated if the quantity of movement had been always equal in equal periods of time? Time must in that case multiply the derangement of strata in the ratio of their antiquity. Indeed, the numerous exceptions to the above rule which we find in nature, present at first sight the only objection to the hypothesis of uniformity. For the more ancient formations remain in many places horizontal, while in others

much newer strata are curved and vertical. This apparent anomaly, however, will be seen in the next chapter to depend on the irregular manner in which the volcanic and subterranean agency affect different parts of the earth in succession, being often renewed again and again in certain areas, while others remain during the whole time at rest.

That the more impressive effects of subterranean power, such as the upheaval of mountain-chains, are due to multiplied convulsions of moderate intensity rather than to a few paroxysmal explosions, will be naturally inferred, when the gradual and intermittent development of volcanic eruptions in times past is once admitted. It is no longer disputed that these eruptions have their source in the same causes as those to which earthquakes and the permanent rise and fall of land are due; the admission, therefore, that one of the two volcanic or subterranean processes has gone on gradually, draws with it the conclusion that the effects of the other have been elaborated by slow degrees.

Faults. — The same reasoning is applicable to great *faults*, or those striking instances of the upthrow or downthrow of large masses of rock, which have been often thought to imply tremendous catastrophes wholly foreign to the ordinary course of nature. Thus we have in England a fault, in which the vertical displacement is between 600 and 1000 feet, and the horizontal extent of the movement thirty miles or more, the width of the fissure since filled up with rubbish varying from ten to fifty feet. But when we inquire into the proofs of the mass having risen or fallen suddenly on the one side of this great rent several hundred feet above or below the rock with which it was once continuous on the other side, we find the evidence defec-

tive. There are grooves, it is said, and scratches on the rubbed and polished walls, which have often one common direction, favouring the theory that the movement was accomplished by a single stroke, and not by a series of interrupted movements. But, in fact, the striæ are not always parallel in such cases, but often irregular, and sometimes the stones and earth which are in the middle of the fault or fissure have been polished and striated by friction, showing that there have been slidings subsequent to the first introduction of the fragmentary matter. Nor should we forget that the last movement must always tend to obliterate the signs of previous trituration, so that neither its instantaneousness nor the uniformity of its direction can be inferred from the parallelism of the striæ that have been last produced.

When rocks have been once fractured, and freedom of motion communicated to detached portions of them, these will naturally continue to yield in the same direction, if the process of upheaval or of undermining be repeated again and again. The incumbent mass will always give way along the lines of least resistance, or where it was formerly rent asunder. Probably, the effects of reiterated movement, whether upward or downward, in a fault, may be undistinguishable from those of a single and instantaneous rise or subsidence, and the same may be said of the rising or falling of continental masses, such as Sweden or Greenland, which we know to take place slowly and insensibly.

The difficulty of reducing within narrow limits the quantity of time which may have elapsed during the origin of great faults and mountain-chains will be better understood, when the reader has perused the concluding pages of the twelfth chapter.

CHAPTER XI.

DOCTRINE OF ALTERNATE PERIODS OF REPOSE AND CONVULSION, AND OF SUDDEN REVOLUTIONS IN THE ANIMATE WORLD, CONTROVERTED.

Observed facts in which this doctrine has originated — These may be equally explained by supposing a uniform and uninterrupted series of changes in the animate and inanimate world — Threefold consideration of this subject; first, in reference to the living creation, extinction of species, and origin of new animals and plants; secondly, in reference to the changes produced in the earth's crust by the continuance of subterranean movements in certain areas, and their transference after long periods to new areas; thirdly, in reference to the laws which govern the formation of fossiliferous strata, and the shifting of the areas of sedimentary deposition — Concluding remarks on the combined influence of all these modes and causes of change in producing breaks and chasms in the chain of records — These breaks independent both of general and local catastrophes, and of crises in the animate world.

Origin of the doctrine of alternate periods of repose and disorder. — It has been truly observed, that when we arrange the fossiliferous formations in chronological order, they constitute a broken and defective series of monuments: we pass, without any intermediate gradations, from systems of strata which are horizontal to other systems which are highly inclined, from rocks of peculiar mineral composition to others which have a character wholly distinct, — from one assemblage of organic remains to another, in which frequently all the species, and most of the genera, are different. These

violations of continuity are so common, as to constitute the rule rather than the exception, and they have been considered by many geologists as conclusive in favour of sudden revolutions in the inanimate and animate world. According to the speculations of some writers, there have been in the past history of the planet alternate periods of tranquillity and convulsion, the former enduring for ages, and resembling that state of things now experienced by man; the other brief, transient, and paroxysmal, giving rise to new mountains, seas, and valleys, annihilating one set of organic beings, and ushering in the creation of another.

It will be the object of the present chapter to demonstrate, that these theoretical views are not borne out by a fair interpretation of geological monuments. It is true that in the solid framework of the globe, we have a chronological chain of natural records, and that many links in this chain are wanting, but a careful consideration of all the phenomena will lead to the opinion that the series was originally defective, —that it has been rendered still more so by time — that a great part of what remains is inaccessible to man, and even of that fraction which is accessible nine tenths are to this day unexplored.

How the facts may be explained by assuming a uniform series of changes. — The readiest way, perhaps, of persuading the reader that we may dispense with great and sudden revolutions in the geological order of events, is by showing him how a regular and uninterrupted series of changes in the animate and inanimate world may give rise to such breaks in the sequence, and such unconformability of stratified rocks, as are usually thought to imply convulsions and catas-

trophes. It is scarcely necessary to state, that the assumed order of events must be in harmony with all the conclusions legitimately drawn by geologists from the structure of the earth, and must be equally in accordance with the changes observed by man to be now going on in the living and inorganic creation. It may be necessary in the present state of science to supply some part of the assumed course of nature hypothetically; but if so, this must be done without any violation of probability, and always consistently with the analogy of what is known both of the past and present economy of our system. Although the discussion of so comprehensive a subject must carry the beginner far beyond his depth, it will also, it is hoped, stimulate his curiosity and prepare him to read with advantage some elementary treatise on geology, and lead him to perceive the bearing on that science of the changes now in progress on the earth. At the same time it may be useful in teaching him to understand the intimate connexion between the second and third books of this work, the former of which is occupied with the changes of the inorganic, the latter with those of the organic creation.

In pursuance, then, of the plan above proposed, I shall consider in this chapter, first, what may be the course of fluctuation in the animate world; secondly, the mode in which subterranean movements affect the earth's crust in the lapse of ages; and, thirdly, the laws which regulate the deposition of sediment.

UNIFORMITY OF CHANGE CONSIDERED FIRST IN REFERENCE TO THE LIVING CREATION.

First, in regard to the vicissitudes of the living creation, all are agreed that the sedimentary strata

found in the earth's crust are divisible into a variety of groups, more or less dissimilar in their organic remains and mineral composition. The conclusion universally drawn from the study and comparison of these fossiliferous groups is this, that at successive periods, distinct tribes of animals and plants have inhabited the land and waters, and that the organic types of the newer formations are more analogous to species now existing, than those of more ancient rocks. If we then turn to the present state of the animate creation, and inquire whether it has now become fixed and stationary, we discover that, on the contrary, it is in a state of continual flux — that there are many causes in action which tend to the extinction of species, and which are conclusive against the doctrine of their unlimited durability. But natural history has been successfully cultivated for so short a period, that a few examples only of local, and perhaps but one of absolute extirpation can as yet be proved, and these only where the interference of man has been conspicuous. It will nevertheless appear evident, from the facts and arguments detailed in the third book (from the fifth to the tenth chapters inclusive) that man is not the only exterminating agent; and that, independently of his intervention, the annihilation of species is promoted by the multiplication and gradual diffusion of every animal or plant. It will also appear in the same book, that every alteration in the physical geography and climate of the globe cannot fail to have the same tendency. If we proceed still further, and inquire whether new species are substituted from time to time for those which die out, and whether there are certain laws appointed by the Author of Nature, to regulate such new creations, we find that the period

of human observation is as yet too short to afford data for determining so weighty a question. All that can be done is to show, that the successive introduction of new species may be a constant part of the economy of the terrestrial system, without our having any right to expect that we should be in possession of direct proof of the fact. The appearance again and again of new species may easily have escaped detection, since the numbers of known animals and plants have augmented so rapidly within the memory of persons now living, as to have doubled in some classes, and quadrupled in others. It will also be remarked in the sequel (Book III. Chap. xi.), that it must always be more easy if species proceed originally from single stocks, to prove that one which formerly abounded in a given district has ceased to be, than that another has been called into being for the first time. If, therefore, there be as yet only one unequivocal instance of extinction, namely, that of the dodo, it is scarcely reasonable as yet to hope that we should be cognizant of a single instance of the first appearance of some new species.

Recent origin of man, and gradual approach in the tertiary fossils of successive periods from an extinct to the recent fauna. — The geologist, however, if required to advance some fact which may lend countenance to the opinion that in the most modern times, that is to say, after the greater part of the existing fauna and flora were established on the earth there has still been a new species superadded, may point to man himself as furnishing the required illustration, — for man must be regarded by the geologist as a creature of yesterday, not merely in reference to the history of the organic world, but also in relation

to that particular state of the animate creation of which he forms a part. The comparatively modern introduction of the human race is proved by the absence of the remains of man and his works, not only from all strata containing a certain proportion of fossils of extinct species, but even from a large part of the newest strata, in which all the fossil individuals are referable to species still living.

To enable the reader to appreciate the full force of this evidence, I shall give a slight sketch of the information which we have obtained from the more modern strata, respecting the fluctuations of the animate world in times immediately antecedent to the appearance of man.

In tracing the series of fossiliferous formations from the most ancient to the more modern, the first deposits in which we meet with assemblages of organic remains, having a near analogy to the fauna of certain parts of the globe in our own time, are those commonly called tertiary. Even in the Eocene, or oldest subdivision of these tertiary formations, some few of the testacea belong to existing species, although almost all of them, and apparently all the associated vertebrata, are now extinct. These Eocene strata are succeeded by a great number of more modern deposits, which depart gradually in the character of their fossils from the Eocene type, and approach more and more to that of the living creation. In the present state of science, it is chiefly by the aid of shells that we are enabled to arrive at these results, for of all classes the testacea are the most generally diffused in a fossil state, and may be called the medals principally employed by nature in recording the chronology of past events. In the Miocene deposits,

which succeed next to the Eocene, we begin to find a considerable number, although still a minority, of recent species, intermixed with some fossils common to the preceding epoch. We then arrive at the Pliocene strata, in which species now contemporary with man begin to preponderate, and in the newest of which nine tenths of the fossils agree with species still inhabiting the neighbouring sea.

In thus passing from the older to the newer members of the tertiary system we meet with many chasms, but none which separate entirely, and by a broad line of demarcation, one state of the organic world from another. There are no signs of an abrupt termination of one fauna and flora, and the starting into life of new and wholly distinct forms. Although we are far from being able to demonstrate geologically an insensible transition from the Eocene to the recent fauna, yet we may affirm that the more we enlarge and perfect our survey of Europe the more nearly do we approximate to such a continuous series, and the more gradually are we conducted from times when many of the genera and nearly all the species were extinct, to those in which scarcely a single species flourished which we do not know to exist at present.

The great physical revolutions which the surface of Europe has undergone, within the times above adverted to, were spoken of in the description of the map of Europe (p. 211.). Changes, of a similar kind, continued down to a period when the recent testacea predominated to the almost entire exclusion of the extinct. Thus we observe in Sicily a lofty table-land and hills, sometimes rising to the height of 3000 feet, capped with a limestone, in which nine tenths of the testacea are specifically identical with those now

inhabiting the Mediterranean. These calcareous and other argillaceous strata of the same age are intersected by deep valleys which have been gradually formed by denudation, but have not varied materially in width or depth since Sicily was first colonized by the Greeks. The limestone, moreover, which is of so late a date in geological chronology, was quarried for building those ancient temples of Girgenti and Syracuse, of which the ruins carry us back to a remote era in human history. If we are lost in conjectures when speculating on the ages required to lift up these formations to the height of several thousand feet above the sea, how much more remote must be the era when the same rocks were gradually formed beneath the waters?

Post-tertiary formations anterior to man. — Neither in the Sicilian formation above mentioned, nor in any others in which a slight per-centage of existing species occur, have any remains of man or his works been as yet detected. It is still more remarkable that deposits of a later date, which may be called post-tertiary (the fossils which they contain agreeing entirely with species of the neighbouring sea), exhibit no memorials of the human race, or of articles fabricated by the hand of man. Some of these strata pass by the name of "raised beaches," occurring at moderate elevations on the coasts of England, Scotland, and Ireland. Other examples are met with on a more extended scale in Scandinavia, as at the height of 200 feet at Uddevalla in Sweden, and at twice that elevation, near Christiania, in Norway, also at an altitude of 600 or 700 feet, in places farther north. They consist of beds of sand and clay, filling hollows in a district of granite and gneiss, and they must closely resemble the accumulations of shelly matter now in progress at the bottom

of the Norwegian fiords. The rate at which the land is now rising in Scandinavia is far too irregular in different places to afford a safe standard for estimating the minimum of time required for the upheaval of the fundamental granite, and its marine shelly covering, to the height of so many hundred feet; but according to the greatest average of five or six feet in a century, the period required would be very considerable, and the whole of it, as well as the antecedent epoch of submergence, seems to have preceded the introduction of man, at least into these parts of the earth.

There are other post-tertiary formations of fluviatile origin, in the centre of Europe, in which the absence of human remains is perhaps still more striking, because, when formed, they must have been surrounded by dry land. I allude to the silt or *loess* of the basin of the Rhine, which must have gradually filled up the great valley of that river since the time when its waters, and the contiguous lands, were inhabited by the existing species of freshwater and terrestrial mollusks. Showers of ashes, thrown out by some of the last eruptions of the Eifel volcanos, fell during the deposition of this fluviatile silt, and were interstratified with it. But these volcanos became exhausted, the valley was re-excavated through the silt, and again reduced to its present form before the period of human history. The study, therefore, of this shelly silt reveals to us the history of a long series of events, which occurred after the testacea now living inhabited the land and rivers of Europe, and the whole terminated without any signs of the coming of man into that part of the globe.

To conclude, it appears that, in going back from the recent to the Eocene period, we are carried by many

successive steps from the fauna now contemporary with man to an assemblage of fossil species wholly different from those now living. In this retrospect we have not yet succeeded in tracing back a perfect transition from the recent to an extinct fauna; but there are so many species in common to the groups which stand next in succession as to show that there is no great chasm, no signs of a crisis when one class of organic beings was annihilated to give place suddenly to another. This analogy, therefore, derived from a period of the earth's history which can best be compared with the present state of things, and more thoroughly investigated than any other, leads to the conclusion that the extinction and creation of species has been and is the result of a slow and gradual change in the organic world.

UNIFORMITY OF CHANGE CONSIDERED, SECONDLY, IN REFERENCE TO SUBTERRANEAN MOVEMENTS.

To pass on to another of the three topics before proposed for discussion, the reader will find, in the account given in the second book of the earthquakes recorded in history, that certain countries have, from time immemorial, been rudely shaken again and again, while others, comprising by far the largest part of the globe, have remained, to all appearance, motionless. In the regions of convulsion rocks have been rent asunder, the surface has been forced up into ridges, chasms have opened, or the ground throughout large spaces has been permanently lifted up above or let down below its former level. In the regions of tranquillity some areas have remained at rest, but others have been ascertained by a comparison of measure-

ments, made at different periods, to have risen by an insensible motion, as in Sweden, or to have subsided very slowly, as in Greenland. That these same movements, whether ascending or descending, have continued for ages in the same direction has been established by geological evidence. Thus, we find both on the east and west coast of Sweden, that ground which formerly constituted the bottom of the Baltic and of the ocean has been lifted up to an elevation of several hundred feet above high-water mark. The rise within the historical period has not amounted to many yards, but the greater extent of antecedent upheaval is proved by the occurrence in inland spots, several hundred feet high, of deposits filled with fossil shells of species now living either in the ocean or the Baltic.

To detect proofs of slow and gradual subsidence must in general be more difficult; but the theory which accounts for the form of circular coral reefs and lagoon islands, and which will be explained in the last chapter of the third book, will satisfy the reader that there are spaces on the globe, several thousand miles in circumference, throughout which the downward movement has predominated for ages, and yet the land has never, in a single instance, gone down suddenly for several hundred feet at once. Yet geology demonstrates that the persistency of subterranean movements in one direction has not been perpetual throughout all past time. There have been great oscillations of level by which a surface of dry land has been submerged to a depth of several thousand feet, and then at a period long subsequent raised again and made to emerge. Nor have the regions now motionless been always at rest; and some of those which are at present the theatres of reiterated earthquakes have formerly

enjoyed a long continuance of tranquillity. But although disturbances have ceased after having long prevailed, or have recommenced after a suspension for ages, there has been no universal disruption of the earth's crust or desolation of the surface since times the most remote. The non-occurrence of such a general convulsion is proved by the perfect horizontality now retained by some of the most ancient fossiliferous strata throughout wide areas.

Inferences derived from unconformable strata.—That the subterranean forces have visited different parts of the globe at successive periods is inferred chiefly from the unconformability of strata belonging to groups oı different ages. Thus, for example, on the borders of Wales and Shropshire we find the slaty beds of the ancient Silurian system curved and vertical, while the beds of the overlying Carboniferous shale and sandstone are horizontal. All are agreed, that in such a case the older set of strata had suffered great dislocation before the deposition of the newer or Carboniferous beds, and that these last have never since been convulsed by any movements of excessive violence. But the strata of the inferior group suffered only a local derangement, and rocks of the same age are by no means found every where in a curved or vertical position. In various parts of Europe, and particularly near Lake Wener, in the south of Sweden, beds of the same Silurian system maintain the most perfect horizontality, and a similar observation may be made respecting limestones and shales of the like antiquity in the great lake district of Canada and the United States. They are still as flat and horizontal as when first formed, yet since their origin not only have most of the actual mountain chains been uplifted,

but the very rocks of which those mountains are composed have been formed.

It would be easy to multiply instances of similar unconformability in formations of other ages, but a few more will suffice. The Coal-measures before alluded to as horizontal on the borders of Wales are vertical in the Mendip Hills in Somersetshire, where the overlying beds of the New Red Sandstone are horizontal. Again, in the Wolds of Yorkshire the last-mentioned sandstone supports on its curved and inclined beds the horizontal Chalk. The Chalk again is vertical on the flanks of the Pyrenees, and the tertiary strata repose unconformably upon it.

Consistency of local disturbances with general uniformity. — As almost every country supplies illustrations of the same phenomena, they who advocate the doctrine of alternate periods of disorder and repose may appeal to the facts above described, as proving that every district has been by turns convulsed by earthquakes, and then respited for ages from convulsions. But so it might with equal truth be affirmed, that every part of Europe has been visited alternately by winter and summer, although it has always been winter and always summer in some part of the planet, and neither of these seasons has ever reigned simultaneously over the entire globe. They have been always shifting about from place to place; but the vicissitudes which recur thus annually in a single spot are never allowed to interfere with the invariable uniformity of seasons throughout the whole planet.

So, in regard to subterranean movements, the theory of the perpetual uniformity of the force which they exert on the earth's crust is quite consistent with the admission of their alternate development and suspen-

sion for indefinite periods within limited geographical areas.

UNIFORMITY OF CHANGE CONSIDERED, THIRDLY, IN REFERENCE TO SEDIMENTARY DEPOSITION.

It now remains to speak of the laws governing the deposition of new strata. If we survey the surface of the globe we immediately perceive that it is divisible into areas of deposition and non-deposition, or, in other words, at any given time there are spaces which are the recipients, others which are not the recipients of sedimentary matter. No new strata, for example, are thrown down on dry land, which remains the same from year to year; whereas, in many parts of the bottom of seas and lakes, mud, sand, and pebbles are annually spread out by rivers and currents. There are also great masses of limestone growing in some seas, or in mid ocean, chiefly composed of corals and shells.

No sediment deposited on dry land.—As to the dry land, so far from being the receptacle of fresh accessions of matter, it is exposed almost every where to waste away. Forests may be as dense and lofty as those of Brazil, and may swarm with quadrupeds, birds, and insects, yet at the end of ten thousand years one layer of black mould, a few inches thick, may be the sole representative of those myriads of trees, leaves, flowers, and fruits, those innumerable bones and skeletons of birds, quadrupeds, and reptiles, which tenanted the fertile region. Should this land be at length submerged, the waves of the sea may wash away in a few hours the scanty covering of mould, and it may merely impart a darker shade of colour to the next stratum of marl, sand, or other matter newly thrown down. So also at the bottom of the ocean where no sediment is accumulating, sea-weed, zoophytes, fish, and even shells,

may multiply for ages and decompose, leaving no vestige of their form or substance behind. Their decay, in water, although more slow, is as certain and eventually as complete as in the open air. Nor can they be perpetuated for indefinite periods in a fossil state unless imbedded in some matrix which is impervious to water, or which at least does not allow a free percolation of that fluid, impregnated as it usually is with a slight quantity of carbonic or other acid. Such a free percolation may be prevented either by the mineral nature of the matrix itself, or by the superposition of an impermeable stratum; but if unimpeded, the fossil shell or bone will be dissolved and removed, particle after particle, and thus entirely effaced, unless petrifaction or the substitution of mineral for organic matter happen to take place.

That there has been land as well as sea at all former geological periods, we know from the fact, that fossil trees and terrestrial plants are imbedded in rocks of every age. Occasionally lacustrine and fluviatile shells, insects, or the bones of amphibious or land reptiles, point to the same conclusion. The existence of dry land at all periods of the past implies, as before mentioned, the partial deposition of sediment, or its limitation to certain areas, and the next point to which I shall call the reader's attention is the shifting of these areas from one region to another.

First, then, variations in the site of sedimentary deposition are brought about independently of subterranean movements. There is always a slight change from year to year, or from century to century. The sediment of the Rhone, for example, thrown into the lake of Geneva is now conveyed a spot a mile and a half distant from that where accumulated in the tenth century, and six miles

from the point where the delta began originally to form. We may look forward to the period when this lake will be filled up, and then the distribution of the transported matter will be suddenly altered, for the mud and sand brought down from the Alps will thenceforth, instead of being deposited near Geneva, be carried nearly 200 miles southwards, where the Rhone enters the Mediterranean.

In the deltas of large rivers, such as those of the Ganges and Indus, the mud is first carried down for many centuries through one arm, and on this being stopped up it is discharged by another, and may then enter the sea at a point 50 or 100 miles distant from its first receptacle. The direction of marine currents is also liable to be changed by various accidents, as by the heaping up of new sand banks, or the wearing away of cliffs and promontories.

But, secondly, all these causes of fluctuation in the sedimentary areas are entirely subordinate to those great upward or downward movements of land which have been already described as prevailing over large tracts of the globe. By such elevation or subsidence certain spaces are gradually submerged, or made gradually to emerge:—in the one case sedimentary deposition may be suddenly renewed after having been suspended for ages, in the other as suddenly made to cease after having continued for an indefinite period.

Causes of variation in mineral character of successive sedimentary groups. — If deposition be renewed after a long interval, the new strata will usually differ greatly from the sedimentary rocks previously formed in the same place, and especially if the older rocks have suffered derangement, which implies a change in the physical geography of the district since the previous

conveyance of sediment to the same spot. It may happen, however, that, even when the inferior group is horizontal and conformable to the upper strata, these last may still differ entirely in mineral character, because since the origin of the older formation the geography of some distant country has been altered. In that country rocks before concealed may have become exposed by denudation, volcanos may have burst out and covered the surface with scoriæ and lava, or new lakes may have been formed by subsidence; and other fluctuations may have occurred by which the materials brought down from thence by rivers to the sea have acquired a distinct mineral character.

It is well known that the stream of the Mississippi is charged with sediment of a different colour from that of the Arkansas and Red Rivers, which are tinged with red mud, derived from rocks of porphyry in "the far west." The waters of the Uruguay, says Darwin, draining a granitic country, are clear and black, those of the Parana red.* The mud with which the Indus is loaded, says Burnes, is of a clayey hue, that of the Chenab, on the other hand, is reddish, that of the Sutlege is more pale.† The same causes which make these several rivers, sometimes situated at no great distance the one from the other, to differ greatly in the character of their sediment, will make the waters draining the same country at different epochs, especially before and after great revolutions in physical geography, to be entirely dissimilar. It is scarcely necessary to add, that marine currents will be affected in an analogous manner in consequence of the formation of new shoals, the emergence of new islands,

* Darwin's Journal, p. 163.

† Journ. Roy. Geograph. Soc. vol. iii. p. 142.

the subsidence of others, the gradual waste of neighbouring coasts, the growth of new deltas, the increase of coral reefs, and other changes.

Why successive sedimentary groups contain distinct fossils. — If, in the next place, we assume, for reasons before stated, a continual extinction of species and introduction of others into the globe, it will then follow that the fossils of strata formed at two distant periods on the same spot will differ even more certainly than the mineral composition of the same. For rocks of the same kind have sometimes been reproduced in the same district after a long interval of time, whereas there are no facts leading to the opinion that species which have once died out have ever been reproduced. The submergence then of land must be often attended by the commencement of a new class of sedimentary deposits, characterized by a new set of fossil animals and plants, while the reconversion of the bed of the sea into land may arrest at once and for an indefinite time the formation of geological monuments. Should the land again sink strata will again be formed; but one or many entire revolutions in animal or vegetable life may have been completed in the interval.

Conditions requisite for the original completeness of a fossiliferous series. — If we infer, for reasons before explained, that fluctuations in the animate world are brought about by the slow and successive removal and creation of species, we shall be convinced that a rare combination of circumstances alone can give rise to such a series of strata as will bear testimony to a gradual passage from one state of organic life to another. To produce such strata nothing less will be requisite than the fortunate coincidence of the following conditions: first, a never-failing supply of sediment in the same

region throughout a period of vast duration; secondly, the fitness of the deposit in every part for the permanent preservation of imbedded fossils; and, thirdly, a gradual subsidence to prevent the sea or lake from being filled up and converted into land.

It will appear in the chapter on coral reefs (Book III. chap. xviii.) that, in certain parts of the Pacific and Indian oceans, most of these conditions, if not all, are complied with, and the constant growth of coral, keeping pace with the sinking of the bottom of the sea, seems to have gone on so slowly, for such indefinite periods, that the signs of a gradual change in organic life might probably be detected in that quarter of the globe, if we could explore its submarine geology. Instead of the growth of coralline limestone, let us suppose, in some other place, the continuous deposition of fluviatile mud and sand, such as the Ganges and Burrampooter have poured for thousands of years into the Bay of Bengal. Part of this bay, although of considerable depth, might at length be filled up before an appreciable amount of change was effected in the fish, mollusca, and other inhabitants of the sea and neighbouring land. But, if the bottom be lowered by sinking at the same rate that it is raised by fluviatile mud, the bay can never be turned into dry land. In that case one new layer of matter may be superimposed upon another for a thickness of many thousand feet, and the fossils of the inferior beds may differ greatly from those entombed in the uppermost, yet every intermediate gradation may be indicated in the passage from an older to a newer assemblage of species. Granting, however, that such an unbroken sequence of monuments may thus be elaborated in certain parts of the sea, and that the strata happen

to be all of them well adapted to preserve the included fossils from decomposition, how many accidents must still concur before these submarine formations will be laid open to our investigation. The whole deposit must first be raised several thousand feet, in order to bring into view the very foundation; and during the process of exposure the superior beds must not be entirely swept away by denudation.

In the first place, the chances are as three to one against the mere emergence of the mass above the waters, because three fourths of the globe are covered by the ocean. But if it be upheaved and made to constitute part of the dry land, it must also, before it can be available for our instruction, become part of that area already surveyed by geologists; and this area comprehends perhaps less than a tenth of the whole earth. In this small fraction of land already explored, and still very imperfectly known, we are required to find a set of strata, originally of limited extent, and probably much lessened by subsequent denudation.

Yet it is precisely because we do not encounter at every step the evidence of such gradations from one state of the organic world to another, that so many geologists embrace the doctrine of great and sudden revolutions in the history of the animate world. Not content with simply availing themselves, for the convenience of classification, of those gaps and chasms which here and there interrupt the continuity of the chronological series, as at present known, they deduce, from the frequency of these breaks in the chain of records, an irregular mode of succession in the events themselves both in the organic and inorganic world. But, besides that some links of the chain which once existed are now clearly lost and others concealed

from view, we have good reason to suspect that it was never complete originally. It may undoubtedly be said, that strata have been always forming somewhere, and therefore at every moment of past time nature has added a page to her archives; but, in reference to this subject, it should be remembered that we can never hope to compile a consecutive history by gathering together monuments which were originally detached and scattered over the globe. For as the species of organic beings contemporaneously inhabiting remote regions are distinct, the fossils of the first of several periods which may be preserved in any one country, as in America, for example, will have no connection with those of a second period found in India, and will therefore no more enable us to trace the signs of a gradual change in the living creation, than a fragment of Chinese history will fill up a blank in the political annals of Europe.

How far some of the great violations of continuity which now exist in the chronological table of fossiliferous rocks, will hereafter be removed or lessened, must at present be mere matter of conjecture. The hiatus which exists in Great Britain between the fossils of the Lias and those of the Magnesian Limestone, is supplied in Germany by the rich fauna and flora of the Muschelkalk, Keuper, and Bunter Sandstein, which we know to be of a date precisely intermediate; those three formations being interposed in Germany between others which agree perfectly in their organic remains with our Lias and Magnesian Limestone. Until lately the fossils of the Coal-measures were separated from those of the antecedent Silurian group, by a very abrupt and decided line of demarcation; but recent discoveries have brought to light in Devonshire,

Belgium, the Eifel, and Westphalia, the remains of a fauna of an intervening period. This connecting link is furnished by the fossil shells, fish, and corals of the Devonian or Old Red Sandstone group, and some species of this newly intercalated fauna are found to be common to it and the subjacent Silurian rocks, while other species belong to it in common with the Coal-measures. Whether we shall ever succeed in like manner in diminishing greatly the hiatus which still separates the Cretaceous and Eocene periods in Europe cannot now be foreseen, but we must be prepared to expect, for reasons before stated, that some such chasms will for ever continue to occur in some parts of our sedimentary series.

Concluding remarks on the consistency of the theory of gradual change, with the existence of great breaks in the series. — But to conclude this part of my subject, it is assumed, for reasons above explained, that a slow change of species is in simultaneous operation everywhere throughout the habitable surface of sea and land; whereas the fossilization of plants and animals is confined to those areas where new strata are produced. These areas, as we have seen, are always shifting their position; so that the fossilizing process, by means of which the commemoration of the particular state of the organic world, at any given time, is effected, may be said to move about, visiting and revisiting different tracts in succession.

To make still more clear the supposed working of this machinery, I shall compare it to a somewhat analogous case that might be imagined to occur in the history of human affairs. Let the mortality of the population of a large country represent the successive extinction of species, and the births of new individuals

the introduction of new species. While these fluctuations are gradually taking place every where, suppose commissioners to be appointed to visit each province of the country in succesion, taking an exact account of the number, names, and individual peculiarities of all the inhabitants, and leaving in each district a register containing a record of this information. If, after the completion of one census, another is immediately made on the same plan, and then another, there will, at last, be a series of statistical documents in each province. When those belonging to any one province are arranged in chronological order, the contents of such as stand next to each other will differ according to the length of the intervals of time between the taking of each census. If, for example, there are sixty provinces, and all the registers are made in a single year and renewed annually, the number of births and deaths will be so small, in proportion to the whole of the inhabitants, during the interval between the compiling of two consecutive documents, that the individuals described in such documents will be nearly identical; whereas, if the survey of each of the sixty provinces occupies all the commissioners for a whole year, so that they are unable to revisit the same place until the expiration of sixty years, there will then be an almost entire discordance between the persons enumerated in two consecutive registers in the same province. There are, undoubtedly, other causes besides the mere quantity of time, which may augment or diminish the amount of discrepancy. Thus, at some periods a pestilential disease may have lessened the average duration of human life, or a variety of circumstances may have caused the births to be unusually numerous, and the population to multiply; or, a province may be

suddenly colonized by persons migrating from surrounding districts.

These exceptions may be compared to the accelerated rate of fluctuation in the fauna and flora of a particular region, in which the climate and physical geography, may be undergoing an extraordinary degree of alteration.

But I must remind the reader, that the case above proposed has no pretensions to be regarded as an exact parallel to the geological phenomena which I desire to illustrate; for the commissioners are supposed to visit the different provinces in rotation; whereas the commemorating processes by which organic remains become fossilized, although they are always shifting from one area to another, are yet very irregular in their movements. They may abandon and revisit many spaces again and again, before they once approach another district; and, besides this source of irregularity, it may often happen that, while the depositing process is suspended, denudation may take place, which may be compared to the occasional destruction by fire or other causes of some of the statistical documents before mentioned. It is evident that, where such accidents occur, the want of continuity in the series may become indefinitely great, and that the monuments which follow next in succession will by no means be equidistant from each other in point of time.

If this train of reasoning be admitted, the occasional distinctness of the fossil remains, in formations immediately in contact, would be a necessary consequence of the existing laws of sedimentary deposition and subterranean movement, accompanied by a constant mortality and renovation of species.

As all the conclusions above insisted on are directly

opposed to opinions still popular, I shall add another comparison, in the hope of preventing any possible misapprehension of the argument. Suppose we had discovered two buried cities at the foot of Vesuvius, immediately superimposed upon each other, with a great mass of tuff and lava intervening, just as Portici and Resina, if now covered with ashes, would overlie Herculaneum. An antiquary might possibly be entitled to infer, from the inscriptions on public edifices, that the inhabitants of the inferior and older city were Greeks, and those of the modern town Italians. But he would reason very hastily if he also concluded from these data, that there had been a sudden change from the Greek to the Italian language in Campania. But if he afterwards found *three* buried cities, one above the other, the intermediate one being Roman, while, as in the former example, the lowest was Greek and the uppermost Italian, he would then perceive the fallacy of his former opinion, and would begin to suspect that the catastrophes, by which the cities were inhumed, might have no relation whatever to the fluctuations in the language of the inhabitants; and that, as the Roman tongue had evidently intervened between the Greek and Italian, so many other dialects may have been spoken in succession, and the passage from the Greek to the Italian may have been very gradual; some terms growing obsolete, while others were introduced from time to time.

If this antiquary could have shown that the volcanic paroxysms of Vesuvius were so governed as that cities should be buried one above the other, just as often as any variation occurred in the language of the inhabitants, then, indeed, the abrupt passage from a Greek to a Roman, and from a Roman to an Italian city,

would afford proof of fluctuations no less sudden in the language of the people.

So, in Geology, if we could assume that it is part of the plan of nature to preserve, in every region of the globe, an unbroken series of monuments to commemorate the vicissitudes of the organic creation, we might infer the sudden extirpation of species, and the simultaneous introduction of others, as often as two formations in contact are found to include dissimilar organic fossils. But we must shut our eyes to the whole economy of the existing causes, aqueous, igneous, and organic, if we fail to perceive *that such is not the plan of Nature.*

CHAPTER XII.

SUPPOSSED SUDDEN UPHEAVAL AND PARALLELISM OF CONTEMPORANEOUS MOUNTAIN CHAINS.

Statement of the theory of the sudden upheaval of parallel mountain chains — Objections to the proof of the suddenness of the upheaval, and the contemporaneousness of parallel chains — As large tracts of land are rising or sinking slowly, so narrow zones of land may be pushed up to great heights gradually — Trains of active volcanos not parallel.

The doctrine of the suddenness and universality of the revolutions which the physical geography of the globe has undergone, at succcessive periods of the past, has been thought by some to acquire additional strength from a theory respecting the origin of mountain chains, recently put forth by a distinguished geologist, M. Elie de Beaumont. In an essay on this subject he has attempted to establish two points; first, that a variety of independent chains of mountains have been thrown up suddenly at particular periods; and, secondly, that all the contemporaneous chains thus thrown up preserve a parallelism the one to the other, even in the most distant regions.

These opinions, and others by which they are accompanied, are so adverse to the views advocated in the foregoing chapter, and to the method of theorizing in geology which I have recommended, that I am desirous of explaining the grounds of my dissent,

a course which I feel myself the more called upon to adopt, as the generalizations alluded to are those of a skilful writer, and an original observer of great talent and experience. I shall begin, therefore, by giving a brief summary of the principal propositions laid down in the work above referred to.

1st. M. de Beaumont supposes, "that in the history of the earth there have been long periods of comparative repose, during which the deposition of sedimentary matter has gone on in regular continuity; and there have also been short periods of paroxysmal violence, during which that continuity was broken.

"2dly. At each of these periods of violence or 'revolution' in the state of the earth's surface a great number of mountain-chains have been formed suddenly.

"3dly. All the chains thrown up by a particular revolution have one uniform direction, being parallel to each other within a few degrees of the compass, even when situated in remote regions; but the chains thrown up at different periods have, for the most part, different directions.

"4thly. Each 'revolution,' or, as it is sometimes termed, 'frightful convulsion,' has fallen in with the date of another geological phenomenon; namely, 'the passage from one independent sedimentary formation to another,' characterized by a considerable difference in 'organic types.'

"5thly. There has been a recurrence of these paroxysmal movements from the remotest geological periods; and they may still be reproduced, and the repose in which we live may hereafter be broken by the sudden upthrow of another system of parallel chains of mountains.

"6thly. We may presume that one of these revolutions has occurred within the historical era, when the Andes were upheaved to their present height; for that chain is the best defined and least obliterated feature observable in the present exterior configuration of the globe, and was probably the last elevated.

"7thly. The instantaneous upheaving from the ocean of great mountain masses must cause a violent agitation in the waters; and the rise of the Andes may, perhaps, have produced that transient deluge which is noticed among the traditions of so many nations.

"Lastly. The successive revolutions above mentioned cannot be referred to ordinary volcanic forces, but may depend on the secular refrigeration of the heated interior of our planet." *

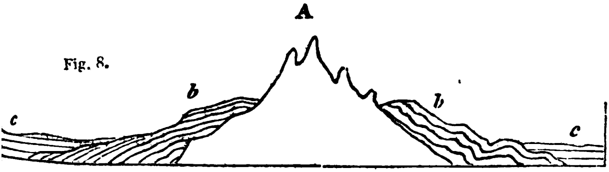
The greater number of the topics enumerated in the above summary have been discussed by anticipation in the last chapter, and I shall now confine myself to what I conceive to be the insufficiency of the proofs adduced in favour of the suddenness of the upthrow, and the contemporaneousness of the origin of the parallel chains referred to. At the same time I may remark, that the great body of facts collected together by M. de Beaumont will always form an invaluable addition to our knowledge, tending as they do to confirm the doctrine that different mountain-chains have been formed in succession, and indicating, at the same

* Ann. des Sci. Nat., Septembre, Novembre, et Décembre, 1829. Revue Française, No. 15. May, 1830. The last edition by M. de B. is in De la Beche's Manual, 3d edit.; and D'Aubuisson, Traité de Géognosie, tom. iii. p. 282. 1835; also referred to by De Beaumont, Instruct. pour l'explor. de l'Algerie, 1838.

time, that there are certain determinate lines of direction or strike in the strata of various countries.

The following may serve as an analysis of the evidence on which the new theory depends. We observe, says M. de Beaumont, "when we attentively examine nearly all mountain chains, that the most recent rocks extend horizontally up to the foot of such chains, as we should expect would be the case if they were deposited in seas or lakes, of which these mountains have partly formed the shores; whilst the other sedimentary beds, tilted up, and more or less contorted, on the flanks of the mountains, rise in certain points even to their highest crests." * There are, therefore, in and adjacent to each chain, two classes of sedimentary rocks, the ancient or inclined beds, and the newer or horizontal. It is evident that the first appearance of the chain itself was an event "intermediate between the period when the beds now upraised were deposited and that when the strata were produced horizontally at its feet."

Fig. 8.



Thus the chain A assumed its present position after the deposition of the strata *b*, which have undergone great movements, and before the deposition of the group *c*, in which the strata have not suffered derangement.

* Phil. Mag. and Annals, No. 58., New Series, p. 242.

If we then discover another chain B, in which we find not only the formation *b*, but the group *c* also,

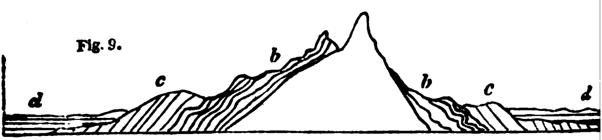


Fig. 9.

disturbed and thrown on its edges, we may infer that the latter chain is of subsequent date to A; for B must have been elevated *after* the deposition of *c*, and before that of the group *d;* whereas A had originated *before* the strata *c* were formed.

It is then argued, that in order to ascertain whether other mountain ranges are of contemporaneous date with A and B, or are referable to *distinct* periods, we have only to inquire whether the inclined and undisturbed sets of strata in each range correspond with or differ from those in the types A and B.

Now all this reasoning is perfectly correct, so long as the periods of the deposition of the particular local groups of strata *b* and *c* are not confounded with the periods during which the animals and plants found fossil in *b* and *c* may have flourished, and provided also that due latitude is given to the term contemporaneous; for this term must be understood to allude, not to a moment of time, but to the interval, whether brief or protracted, which elapsed between two events, namely, between the accumulation of the inclined and that of the horizontal strata.

But, unfortunately, no attempt has been made in the treatise under review to avoid this manifest source of confusion, and hence the very terms of each proposition are equivocal; and the possible length of some of

the intervals is so vast, that to affirm that all the chains raised in such intervals were *contemporaneous* is an abuse of language.

In order to illustrate this argument, I shall select the Pyrenees as an example. This range of mountains, says M. de Beaumont, rose suddenly (à un seul jet *) to its present elevation at a certain epoch in the earth's history, namely, between the deposition of the Chalk and that of the tertiary formations; for the Chalk is seen in vertical, curved, and distorted beds on the flanks of the chain, as the beds *b*, Fig. 8., while the tertiary formations rest upon them in horizontal strata at its base, as *c*, ibid.

The proof then of the extreme suddenness of the convulsion is the supposed shortness of the time which intervened between the formation of the chalk, and the origin of certain tertiary strata.† Yet even if the interval were reducible within these limits, it might comprise an indefinite lapse of time. In strictness of reasoning, however, we cannot permit the author to exclude the whole either of the Cretaceous or tertiary periods, from the possible duration of the interval during all or any part of which the elevation may have taken place. For, in the first place, it cannot be assumed, that the movement of upheaval took place after the close of the Cretaceous period; we can merely say, that it occurred after the deposition of certain strata of that period; secondly, although it be true that the event happened before the formation of certain

* In the last edition of M. de B.'s system (see note above, p. 306.), he only speaks of the convulsion which raised the Pyrenees, as "one of the most violent which the land of Europe ever experienced."

† Phil. Mag. and Annals, No. 53., New Series, p. 243.

tertiary strata now at the base of the Pyrenees, it by no means follows that it preceded the whole tertiary epoch.

The upheaving of the Pyrenees, therefore, may have been going on before the animals of the Chalk period ceased to exist, or when the Maestricht beds were in progress, or during the indefinite ages which may have elapsed between the extinction of the Maestricht animals and the introduction of the Eocene tribes, or during the Eocene epoch, or the rise may have been going on throughout one, or several, or all of these periods.

It would be a purely gratuitous assumption to say that the inclined cretaceous strata (*b*, Fig. 8.) on the flanks of the Pyrenees were the very last which were deposited during the Cretaceous period, or that, as soon as they were upheaved, all or nearly all the species of animals and plants now found fossil in them were suddenly exterminated; yet, unless this can be affirmed, we cannot say that the Pyrenees were not upheaved during the Cretaceous period. Consequently, another range of mountains, at the base of which cretaceous rocks may lie in horizontal stratification, may have been elevated, like the chain A, Fig. 8., during some part of the same great period.

There are mountains in Sicily two or three thousand feet high, the tops of which are composed of limestone, in which nearly all the fossil shells and zoophytes agree specifically with those now inhabiting the Mediterranean. Here, as in many other countries, the deposits now in progress in the sea must inclose shells and other fossils specifically identical with those of the rocks constituting the contiguous land. So there are islands in the Pacific, where a mass of dead coral has emerged to a considerable altitude, while

other portions of the mass remain beneath the sea, still increasing by the growth of living zoophytes and shells. The chalk of the Pyrenees, therefore, may at a remote period have been raised to an elevation of several thousand feet, while the species found fossil in the same chalk still continued to be represented in the fauna of the neighbouring ocean. In a word, we cannot assume that the origin of a new range of mountains caused the Cretaceous period to cease, and served as the prelude to a new order of things in the animate creation.

To illustrate the grave objections above advanced, against the theory considered in the present chapter, let us suppose, that in some country three styles of architecture had prevailed in succession, each for a period of one thousand years; first the Greek, then the Roman, and then the Gothic; and that a tremendous earthquake was known to have occurred in the same district during one of the three periods—a convulsion of such violence as to have levelled to the ground all the buildings then standing. If an antiquary, desirous of discovering the date of the catastrophe, should first arrive at a city where several Greek temples were lying in ruins and half engulphed in the earth, while many Gothic edifices were standing uninjured, could he determine on these data the era of the shock? Could he even exclude any one of the three periods, and decide that it must have happened during one of the other two? Certainly not. He could merely affirm that it happened at some period after the introduction of the Greek style, and before the Gothic had fallen into disuse. Should he pretend to define the date of the convulsion with greater precision, and decide that the earthquake must have

occurred after the Greek and before the Gothic period, that is to say, when the Roman style was in use, the fallacy in his reasoning would be too palpable to escape detection for a moment.

Yet such is the nature of the erroneous induction which I am now exposing. For as, in the example above proposed, the erection of a particular edifice is perfectly distinct from the period of architecture in which it may have been raised, so is the deposition of chalk, or any other set of strata, from the geological epochs characterized by certain fossils to which they may belong.

It is almost superfluous to enter into any farther analysis of the theory of parallelism, because the whole force of the argument depends on the accuracy of the data by which the contemporaneous or non-contemporaneous date of the elevation of two independent chains can be demonstrated. In every case, this evidence, as stated by M. de Beaumont, is equivocal, because he has not included in the possible interval of time between the deposition of the deranged and the horizontal formations part of the periods to which each of those classes of formations are referable. All the geological facts, therefore, adduced by the author may be true, and yet the conclusion that certain chains were or were not simultaneously upraised is by no means a legitimate consequence.

At the same time, it should be observed, that geologists are by no means agreed in regard to the parallelism of the *strike* of all the chains said to be contemporaneous, and many of those referred to in Africa, Asia, India, and South America, are too slightly known, even geographically, to afford data for secure generalization.

Slow upheaval and subsidence of broad areas. — We have already seen that recent observations have unexpectedly disclosed to us the wonderful fact, that large areas, some of them several thousand miles in circumference, comprehending among others Scandinavia, the west coast of South America, and certain archipelagos in the Pacific, are slowly and insensibly rising; while other regions, such as Greenland, and parts of the Pacific and Indian oceans, in which atolls or circular coral islands abound, are as gradually sinking. That all the existing continents and submarine abysses may have originated in movements of this kind, continued throughout incalculable periods of time, is undeniable, and the denudation which the dry land appears every where to have suffered favours the idea that it was raised from the deep by a succession of upward movements, prolonged throughout indefinite periods. For the action of waves and currents on land slowly emerging from the deep affords the only power by which we can conceive so many deep valleys and wide spaces to have been denuded as those which are unquestionably the effects of running water; and one of the soundest objections to the theory of the sudden upthrow of continental masses is, that it deprives us of that great power, so necessary to account for the external configuration of every island and continent.

The uplifting of a narrow zone of land may be equally slow. — But perhaps it may be said that there is no analogy between the slow upheaval of broad plains or table lands, and the manner in which we must presume all mountain chains, with their inclined strata, to have originated. We find, however, certain lofty ranges, like the Andes, in which volcanic action and earthquakes are developed with considerable energy along

determinate lines; and the western part of South America may have risen, century after century, at the rate of several feet, while the Pampas on the east have been raised only a few inches in the same time. In crossing from the Atlantic to the Pacific, in a line passing through Mendoza, we traverse a plain 800 miles broad, the eastern part of which has emerged from beneath the sea at a very modern period. The slope from the Atlantic is at first very gentle, then greater, until the traveller finds, on reaching Mendoza, that he has gained, almost insensibly, a height of 4000 feet. The mountainous district then begins suddenly, and its breadth from Mendoza to the shores of the Pacific is 120 miles, the average height of the principal chain being from 15,000 to 16,000 feet, without including some prominent peaks, which ascend much higher. Now all we require, to explain the origin of the principal inequalities of level here described, is to imagine a zone of more violent movement to the west of Mendoza, and to the east of that place an upheaving force which died away gradually as it approached the Atlantic. In short, we are only called upon to conceive, that the region of the Andes was pushed up four feet in the same period in which the Pampas near Mendoza rose one foot, and the plains near the shores of the Atlantic one inch. In Europe, we have learnt that the land at the North Cape ascends about five feet in a century, while farther to the south the movements diminish in quantity first to a foot, and then, at Stockholm, to three inches in a century, while at points still farther south there is no movement.

Lines of active volcanos not parallel. — I shall now conclude by remarking that, if earthquakes and vol-

canos are both of them the effects of one and the same cause, it is highly probable that earthquakes are developed for ages along narrow zones. And as the trains of active volcanos, although linear, have not all of them one uniform direction, but are sometimes at right angles the one to the other, so is it probable that we shall find in the lines of subterranean convulsion, whether of upheaval or subsidence, a wide deviation from parallelism.

CHAPTER XIII.

DIFFERENCE IN TEXTURE OF THE OLDER AND NEWER ROCKS.

Consolidation of fossiliferous strata — Some deposits originally solid — Transition and slaty texture — Crystalline character of Plutonic and Metamorphic rocks — Theory of their origin — Essentially subterranean — No proofs that they were produced more abundantly at remote periods — Concluding remarks on the identity of the ancient and present system of terrestrial changes.

Another argument in favour of the dissimilarity of the causes operating at remote and recent eras has been derived by many geologists from the more compact, stony, and crystalline texture of the older as compared to the newer rocks.

Consolidation of strata. — This subject may be considered, first, in reference to the fossiliferous strata; and, secondly, in reference to those crystalline and stratified rocks which contain no organic remains, such as gneiss and mica-schist. There can be no doubt that the former of these classes, or the fossiliferous, are generally more compact and stony in proportion as they are more ancient. It is also certain that a great part of them were originally in a soft and incoherent state, and that they have been since consolidated. Thus we find occasionally loose shingle and sand agglutinated firmly together by a ferruginous or siliceous cement, or that lime in solution has been introduced, so as to bind together materials previously incoherent.

The constituents of some beds have probably set and become hard when they emerged from beneath the water, as the marl of Lake Superior, which incloses fresh-water shells, and which is no sooner exposed to the air than it becomes solid, so as only to be broken by a smart blow of the hammer. Organic remains have sometimes suffered a singular transformation, as, for example, where shells, corals, and wood are silicified, their calcareous or ligneous matter having been replaced by nearly pure silica.

But, on the other hand, we observe in certain formations now in progress, particularly in coral reefs, and in deposits from the waters of mineral springs, both calcareous and siliceous, that the texture of rocks may sometimes be stony from the first. This circumstance may account for exceptions to the general rule, not unfrequently met with, where solid strata are superimposed on others of a plastic and incoherent nature, as in the neighbourhood of Paris, where the tertiary formations, consisting often of compact limestone and siliceous grit, are more stony than the subjacent chalk.

It will readily be understood, that the various solidifying causes, including those above enumerated, together with the pressure of incumbent rocks and the influence of subterranean heat, must all of them require time in order to exert their full power. If in the course of ages they modify the aspect and internal structure of stratified deposits, they will give rise to a general distinctness of character in the older as contrasted with the newer formations. But this distinctness will not be the consequence of any original diversity; they will be unlike, just as the wood in the older trees of a forest usually differs in texture and hardness from that of younger individuals of the same species.

Transition texture.—In the original classification of Werner, the highly crystalline rocks, such as granite and gneiss, which contain no organic remains, were called primary, and the fossiliferous strata secondary, while to another class of an age intermediate between the primary and secondary he gave the name of transition. They were termed transition because they partook in some degree in their mineral composition of the nature of the most crystalline rocks, such as gneiss and mica-schist, while they resembled the fossiliferous series in containing occasionally organic remains, and exhibiting evident signs of a mechanical origin. It was at first imagined, that the rocks having this intermediate texture had been all deposited subsequently to the series called primary, and before all the more earthy and fossiliferous formations. But when the relative position and organic remains of these transition rocks were better understood, it was perceived that they did not all belong to one period. On the contrary, the same mineral characters were found in strata of very different ages, and some formations occurring in the Alps, which several of the ablest scholars of Werner had determined to be transition, were ultimately ascertained, by means of their fossil contents and position, to be members of the Cretaceous period. These strata had, in fact, acquired the *transition* texture from the influence of causes which, since their deposition, had modified their internal arrangement.

Texture and origin of Plutonic and metamorphic rocks.—Among the most singular of the changes superinduced on rocks we have occasionally to include the slaty texture, the divisional planes of which sometimes intersect the true planes of stratification, and even pass directly through imbedded fossils. If, then, the crystalline, the

slaty, and other modes of arrangement, once deemed characteristic of certain periods in the history of the earth, have in reality been assumed by fossiliferous rocks of different ages and at different times, we are prepared to inquire whether the same may not be true of the most highly crystalline state, such as that of gneiss, mica-schist, and statuary marble. That the peculiar characteristics of such rocks are really due to a variety of modifying causes has long been suspected by many geologists, and the doctrine has gained ground of late, although a considerable difference of opinion still prevails. According to the original Neptunian theory, all the crystalline formations were precipitated from a universal menstruum or chaotic fluid antecedently to the creation of animals and plants, the unstratified granite having been first thrown down so as to serve as a floor or foundation on which gneiss and other stratified rocks might repose. Afterwards, when the igneous origin of granite was no longer disputed, many conceived that a thermal ocean enveloped the globe, at a time when the first-formed crust of granite was cooling, but when it still retained much of its heat. The hot waters of this ocean held in solution the ingredients of gneiss, mica-schist, hornblende-schist, clay-slate, and marble, which rocks were precipitated, one after the other, in a crystalline form. No fossils could be inclosed in them, the high temperature of the fluid, and the quantity of mineral matter which it held in solution, rendering it unfit for the support of organic beings.

It would be inconsistent with the plan of this work to enter here into a detailed account of what I have elsewhere termed the *metamorphic theory** ; but I may

* See Elements of Geology.

state that it is now demonstrable in some countries that fossiliferous formations, some of them of the age of the Silurian strata, as near Christiania in Norway, others belonging to the Oolitic period, as around Carrara in Italy, have been converted partially into gneiss, mica-schist, and statuary marble. The transmutation has been effected apparently by the influence of subterranean heat, acting under great pressure, or by chemical and electrical causes operating in a manner not yet understood, and which have been termed *Plutonic* action, as expressing in one word all the modifying causes which may be brought into play at great depths, and under conditions never exemplified at the surface. To this Plutonic action the fusion of granite itself in the bowels of the earth, as well as the superinducement of the metamorphic texture into sedimentary strata, must be attributed; and in accordance with these views the age of each metamorphic formation may be said to be twofold, for we have first to consider the period when it originated, as an aqueous deposit, in the form of mud, sand, marl, or limestone; secondly, the date at which it acquired a crystalline texture. The same strata, therefore, may, according to this view, be very ancient in reference to the time of their deposition, and very modern in regard to the period of their assuming the metamorphic character.

No proofs that these crystalline rocks were produced more abundantly at remote periods. — Several modern writers, without denying the truth of the Plutonic or metamorphic theory, still contend that the crystalline and non-fossiliferous formations, whether stratified or unstratified, such as gneiss and granite, are essentially ancient as a class of rocks. They were generated, say they, most abundantly in a primeval state of the

globe, since which time the quantity produced has been always on the decrease, until it became very inconsiderable in the Oolitic and Cretaceous periods, and quite evanescent before the commencement of the tertiary epoch.

Now the justness of these views depends almost entirely on the question whether granite, gneiss, and other rocks of the same order, ever originated at the surface, or whether, according to the opinions above adopted, they are essentially subterranean in their origin, and therefore entitled to the appellation of *hypogene*. If they were formed superficially in their present state, and as copiously in the modern as in the more ancient periods, we ought to see a greater abundance of tertiary and secondary than of primary granite and gneiss; but if we adopt the hypogene theory before explained, their rapid diminution in volume among the visible rocks in the earth's crust in proportion as we investigate the formations of newer date is quite intelligible. If a melted mass of matter be now cooling very slowly at the depth of several miles beneath the crater of an active volcano, it must remain invisible until great revolutions in the earth's crust have been brought about. So also if stratified rocks have been subjected to Plutonic action, and after having been baked or reduced to semi-fusion, are now cooling and crystallizing far under ground, it will probably require the lapse of many periods before they will be forced up to the surface and exposed to view, even at a single point. To effect this purpose there may be need of as great a development of subterranean movement as that which in the Alps, Andes, and Himalaya has raised marine strata containing ammonites to the height of 8000, 14,000, and 16,000 feet.

By parity of reasoning we can hardly expect that any hypogene rocks of the tertiary periods will have been brought within the reach of human observation, seeing that the emergence of such rocks must always be so long posterior to the date of their origin, and still less can formations of this class become generally visible until so much time has elapsed as to confer on them a high relative antiquity. Extensive denudation must also combine with upheaval before they can be displayed at the surface throughout wide areas.

All geologists who reflect on subterranean movements now going on, and the eruptions of active volcanos, are convinced that great changes are now continually in progress in the interior of the earth's crust far out of sight. They must be conscious, therefore, that the inaccessibility of the regions in which these alterations are taking place, compels them to remain in ignorance of a great part of the working of existing causes, so that they can only form vague conjectures in regard to the nature of the products which volcanic heat may elaborate under great pressure.

But when they find in mountain chains of high antiquity that what was once the interior of the earth's crust has since been forced outwards and exposed to view, they will naturally expect, in the examination of those mountainous regions, to have an opportunity of gratifying their curiosity by obtaining a sight not only of the superficial strata of remote eras, but also of the contemporaneous nether-formed rocks. Having recognized therefore in such mountain chains some ancient rocks of aqueous and volcanic origin, corresponding in character to superficial formations of modern date, they will regard any other class of ancient rocks, such as

granite and gneiss, as the *residual phenomena* of which they are in search. These latter rocks will not answer the expectations previously formed of their probable nature and texture, unless they wear a foreign and mysterious aspect, and have in some places been fused or altered by subterranean heat; in a word, unless they differ wholly from the fossiliferous strata deposited at the surface, or from the lava and scoriæ thrown out by volcanos in the open air. It is the total distinctness, therefore, of crystalline formations, such as granite, hornblende-schist, and the rest, from every substance of which the origin is familiar to us, that constitutes their claim to be regarded as the effects of causes now in action in the subterranean regions. They belong not to an order of things which have passed away; they are not the monuments of a primeval period, bearing inscribed upon them in obsolete characters the words and phrases of a dead language; but they teach us that part of the living language of nature which we cannot learn by our daily intercourse with what passes on the habitable surface.

Concluding remarks on the identity of the ancient and present system of terrestrial changes. — I shall now conclude the discussion of a question with which we have been occupied since the beginning of the fifth chapter; namely, whether there has been any interruption, from the remotest periods, of one uniform system of change in the animate and inanimate world. We were induced to enter into that inquiry by reflecting how much the progress of opinion in Geology had been influenced by the assumption that the analogy was slight in kind, and still more slight in degree, between the causes which produced the former revolu-

tions of the globe, and those now in every day operation. It appeared clear that the earlier geologists had not only a scanty acquaintance with existing changes, but were singularly unconscious of their ignorance. With the presumption naturally inspired by this unconsciousness, they had no hesitation in deciding at once that time could never enable the existing powers of nature to work out changes of great magnitude, still less such important revolutions as those which are brought to light by Geology. They, therefore, felt themselves at liberty to indulge their imaginations in guessing at what *might be*, rather than in inquiring *what is;* in other words, they employed themselves in conjecturing what might have been the course of nature at a remote period, rather than in the investigation of what was the course of nature in their own times.

It appeared to them more philosophical to speculate on the possibilities of the past, than patiently to explore the realities of the present; and having invented theories under the influence of such maxims, they were consistently unwilling to test their validity by the criterion of their accordance with the ordinary operations of nature. On the contrary, the claims of each new hypothesis to credibility appeared enhanced by the great contrast, in kind or intensity, of the causes referred to and those now in operation.

Never was there a dogma more calculated to foster indolence, and to blunt the keen edge of curiosity, than this assumption of the discordance between the ancient and existing causes of change. It produced a state of mind unfavourable in the highest degree to the candid reception of the evidence of those minute but incessant alterations which every part of the earth's

surface is undergoing, and by which the condition of its living inhabitants is continually made to vary. The student, instead of being encouraged with the hope of interpreting the enigmas presented to him in the earth's structure, — instead of being prompted to undertake laborious inquiries into the natural history of the organic world, and the complicated effects of the igneous and aqueous causes now in operation, was taught to despond from the first. Geology, it was affirmed, could never rise to the rank of an exact science, — the greater number of phenomena must for ever remain inexplicable, or only be partially elucidated by ingenious conjectures. Even the mystery which invested the subject was said to constitute one of its principal charms, affording, as it did, full scope to the fancy to indulge in a boundless field of speculation.

The course directly opposed to this method of philosophizing consists in an earnest and patient inquiry how far geological appearances are reconcileable with the effect of changes now in progress, or which may be in progress in regions inaccessible to us, and of which the reality is attested by volcanos and subterranean movements. It also endeavours to estimate the aggregate result of ordinary operations multiplied by time, and cherishes a sanguine hope that the resources to be derived from observation and experiment, or from the study of nature such as she now is, are very far from being exhausted. For this reason all theories are rejected which involve the assumption of sudden and violent catastrophes and revolutions of the whole earth, and its inhabitants, — theories which are restrained by no reference to existing analogies, and in which a de-

sire is manifested to cut, rather than patiently to untie, the Gordian knot.

We have now, at least, the advantage of knowing, from experience, that an opposite method has always put geologists on the road that leads to truth,—suggesting views which, although imperfect at first, have been found capable of improvement, until at last adopted by universal consent; while the method, of speculating on a former distinct state of things and causes, has led invariably to a multitude of contradictory systems, which have been overthrown one after the other,—have been found incapable of modification,—and which have often required to be precisely reversed.

The remainder of this work will be devoted to an investigation of the changes now going on in the crust of the earth and its inhabitants. The importance which the student will attach to such researches will mainly depend in the degree of confidence which he feels in the principles above expounded. If he firmly believes in the resemblance or identity of the ancient and present system of terrestrial changes, he will regard every fact collected respecting the causes in diurnal action as affording him a key to the interpretation of some mystery in the past. Events which have occurred at the most distant periods in the animate and inanimate world will be acknowledged to throw light on each other, and the deficiency of our information respecting some of the most obscure parts of the present creation will be removed. For as, by studying the external configuration of the existing land and its inhabitants, we may restore in imagination the appearance of the ·ient continents which have passed away, so may we from the deposits of ancient seas and lakes an

insight into the nature of the subaqueous processes now in operation, and of many forms of organic life, which, though now existing, are veiled from sight. Rocks, also, produced by subterranean fire in former ages, at great depths in the bowels of the earth, present us, when upraised by gradual movements, and exposed to the light of heaven, with an image of those changes which the deep-seated volcano may now occasion in the nether regions. Thus, although we are mere sojourners on the surface of the planet, chained to a mere point in space, enduring but for a moment of time, the human mind is not only enabled to number worlds beyond the unassisted ken of mortal eye, but to trace the events of indefinite ages before the creation of our race, and is not even withheld from penetrating into the dark secrets of the ocean, or the interior of the solid globe; free, like the spirit which the poet described as animating the universe,

——— ire per omnes
Terrasque, tractusque maris, cœlumque profundum.

BOOK II.

CHANGES OF THE INORGANIC WORLD.

Aqueous Causes.

CHAPTER I.

Division of the subject into changes of the organic and inorganic world — Inorganic causes of change divided into aqueous and igneous — Aqueous causes first considered — Destroying and transporting power of running water — Sinuosities of rivers — Two streams when united do not occupy a bed of double surface — Heavy matter removed by torrents and floods — Recent inundations in Scotland — Erosion of chasms through hard rocks — Excavations in the lavas of Etna by Sicilian rivers — Gorge of the Simeto — Gradual recession of the cataracts of Niagara.

Division of the subject. — Geology was defined to be the science which investigates the former changes that have taken place in the organic, as well as in the inorganic kingdoms of nature. As vicissitudes in the inorganic world are most apparent, and as on them all fluctuations in the animate creation must in a great measure depend, they may claim our first consideration. The great agents of change in the organic world may be divided into two principal classes, the aqueous -d the igneous. To the aqueous belong Rivers, ents, Springs, Currents, and Tides; to the igneous, nos and Earthquakes. Both these classes are

instruments of decay as well as of reproduction; but they may also be regarded as antagonist forces. For the aqueous agents are incessantly labouring to reduce the inequalities of the earth's surface to a level; while the igneous are equally active in restoring the unevenness of the external crust, partly by heaping up new matter in certain localities, and partly by depressing one portion, and forcing out another, of the earth's envelope.

It is difficult, in a scientific arrangement, to give an accurate view of the combined effects of so many forces in simultaneous operation; because, when we consider them separately, we cannot easily estimate either the extent of their efficacy, or the kind of results which they produce. We are in danger, therefore, when we attempt to examine the influence exerted singly by each, of overlooking the modifications which they produce on one another; and these are so complicated, that sometimes the igneous and aqueous forces co-operate to produce a joint effect, to which neither of them unaided by the other could give rise, —as when repeated earthquakes unite with running water to widen a valley; or when a thermal spring rises up from a great depth, and conveys the mineral ingredients with which it is impregnated from the interior of the earth to the surface. Sometimes the organic combine with the inorganic causes; as when a reef, composed of shells and corals, protects one line of coast from the destroying power of tides or currents, and turns them against some other point; or when drift timber, floated into a lake, fills a hollow to which the stream would not have had sufficient velocity to convey earthy sediment.

It is necessary, however, to divide our observations

on these various causes, and to classify them systematically, endeavouring as much as possible to keep in view that the effects in nature are mixed, and not simple, as they may appear in an artificial arrangement.

In treating, in the first place, of the aqueous causes, we may consider them under two divisions: first, those which are connected with the circulation of water from the land to the sea, under which are included all the phenomena of rivers and springs; secondly, those which arise from the movements of water in lakes, seas, and the ocean, wherein are comprised the phenomena of tides and currents. In turning our attention to the former division, we find that the effects of rivers may be subdivided into those of a destroying and those of a renovating nature; in the destroying are included the erosion of rocks, and the transportation of matter to lower levels; in the renovating class, the formation of deltas by the influx of sediment, and the shallowing of seas.

Action of running water.—I shall begin, then, by describing the destroying and transporting power of running water, as exhibited by torrents and rivers. It is well known that the lands elevated above the sea attract, in proportion to their volume and density, a larger quantity of that aqueous vapour which the heated atmosphere continually absorbs from the surface of lakes and the ocean. By these means, the higher regions become perpetual reservoirs of water, which descend and irrigate the lower valleys and plains. In consequence of this provision, almost all the water is first carried to the highest regions, and is then made to descend by steep declivities towards the sea; so that it acquires superior velocity, and removes a greater quantity of soil, than it would do if the rain

had been distributed over the plains and mountains equally in proportion to their relative areas. Almost all the water is also made by these means to pass over the greatest distances which each region affords, before it can regain the sea. The rocks also, in the higher regions, are particularly exposed to atmospheric influences, to frost, rain, and vapour, and to great annual alternations of cold and heat, of moisture and desiccation.

Among the most powerful agents of decay may be mentioned that property of water which causes it to expand during congelation; its increase of bulk when converted into ice amounting to no less than one twentieth of the whole volume, so that when water has penetrated into the crevices of the most solid rocks, it rends them open on freezing with mechanical force.* For this reason, although in cold climates the comparative quantity of rain which falls is very inferior, and although it descends more gradually than in tropical regions, yet the severity of frost, and the greater inequalities of temperature, compensate in some degree for this diminished source of degradation. The solvent power of water also is very great, and acts particularly on the calcareous and alkaline elements of stone, especially when it holds carbonic acid in solution, which is abundantly supplied to almost every large river by springs, and is collected by rain from the atmosphere. The oxygen of the atmosphere is also gradually absorbed by all animal and vegetable productions, and by almost all mineral masses exposed to the open air. It gradually destroys the equilibrium of the elements of rocks, and tends to reduce into powder,

* Quart. Journ. of Sci., &c. new series, No. xiii. p. 194.

and to render fit for soils, even the hardest aggregates belonging to our globe.*

When earthy matter has once been intermixed with running water, a new mechanical power is obtained by the attrition of sand and pebbles, borne along with violence by a stream. Running water charged with foreign ingredients being thrown against a rock, excavates it by mechanical force, sapping and undermining till the superincumbent portion is at length precipitated into the stream. The obstruction causes a temporary ponding back of the water, which then sweeps down the barrier.

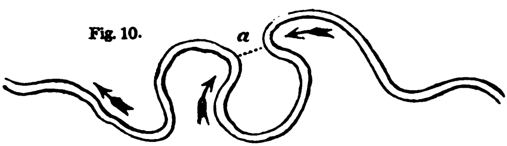
Sinuosities of rivers.—By a repetition of these landslips the ravine is widened into a small, narrow valley, in which sinuosities are caused by the deflexion of the stream first to one side and then to the other. The unequal hardness of the materials through which the channel is eroded tends partly to give new directions to the lateral force of excavation. When by these, or by accidental shiftings of the alluvial matter in the channel, and numerous other causes, the current is made to cross its general line of descent, it eats out a curve in the opposite bank, or in the side of the hills bounding the valley, from which curve it is turned back again at an equal angle, so that it recrosses the line of descent, and gradually hollows out another curve lower down in the opposite bank, till the whole sides of the valley, or river-bed, present a succession of salient and retiring angles. Among the causes of deviation from a straight course by which torrents and rivers tend in mountainous regions to widen the valleys through which they flow, may be mentioned the con-

* Sir H. Davy, Consolations in Travel, p. 271.

fluence of lateral torrents, swollen irregularly at different seasons by partial storms, and discharging at different times unequal quantities of sand, mud, and pebbles, into the main channel.

When the tortuous flexures of a river are extremely great, the aberration from the direct line of descent is often restored by the river cutting through the isthmus which separates two neighbouring curves. Thus, in the annexed diagram, the extreme sinuosity of the

Fig. 10.



river has caused it to return for a brief space in a contrary direction to its main course, so that a peninsula is formed, and the isthmus (at *a*) is consumed on both sides by currents flowing in opposite directions. In this case an island is soon formed, — on either side of which a portion of the stream usually remains.

Transporting power of water. — In regard to the transporting power of water, we may often be surprised at the facility with which streams of a small size, and descending a slight declivity, bear along coarse sand and gravel; for we usually estimate the weight of rocks in air, and do not reflect on their comparative buoyancy when submerged in a denser fluid. The specific gravity of many rocks is not more than twice that of water, and very rarely more than thrice, so that almost all the fragments propelled by a stream have lost a third, and many of them half, of what we usually term their weight.

It has been proved by experiment, in contradiction to the theories of the earlier writers on hydrostatics, to be a universal law, regulating the motion of running water, that the velocity at the bottom of the stream is every where less than in any part above it, and is greatest at the surface. Also, that the superficial particles in the middle of the stream move swifter than those at the sides. This retardation of the lowest and lateral currents is produced by friction; and when the velocity is sufficiently great, the soil composing the sides and bottom gives way. A velocity of three inches per second at the bottom is ascertained to be sufficient to tear up fine clay, — six inches per second, fine sand, — twelve inches per second, fine gravel, — and three feet per second, stones of the size of an egg.*

When this mechanical power of running water is considered, we are prepared for the transportation of large quantities of gravel, sand, and mud, by the torrents and rivers which descend with great velocity from mountainous regions. But a question naturally arises, how the more tranquil rivers of the valleys and plains, flowing on comparatively level ground, can remove the prodigious burden which is discharged into them by their numerous tributaries, and by what means they are enabled to convey the whole mass to the sea. If they had not this removing power, their channels would be annually choked up, and the valleys of the lower country, and plains at the base of mountain-chains, would be continually strewed over with fragments of rock and sterile sand. But this evil is prevented by a general law regulating the conduct of

* Encyc. Brit. — art. Rivers.

running water,—that two equal streams do not, when united, occupy a bed of double surface. In other words, when several rivers unite into one, the superficial area of the fluid mass is far less than that previously occupied by the separate streams. The collective waters, instead of spreading themselves out over a larger horizontal space, contract themselves into a column of which the height is greater relatively to its breadth. Hence the main current is often accelerated in the lower country, even where the slope of the river's bed is lessened, a smaller proportion of the whole being retarded by friction against the bottom and sides of the channel, and in this manner the stream is enabled to force its way against all obstructions, and gradually to remove the matter swept down into it from the upland regions.

It not unfrequently happens, as will be afterwards demonstrated by examples, that two large rivers, after their junction, have only the *surface* which one of them had previously; and even in some cases their united waters are confined in a narrower bed than each of them filled before. By this beautiful adjustment, the water which drains the interior country is made continually to occupy less room as it approaches the sea; and thus the most valuable part of our continents, the rich deltas, and great alluvial plains, are prevented from being constantly under water.*

River-floods in Scotland, 1829.—Many remarkable illustrations of the power of running water in moving stones and heavy materials were afforded by the storm and floods which occurred on the 3d and 4th of August, 1829, in Aberdeenshire and other counties in Scotland.

* See article Rivers, Encyc. Brit.

The elements during this storm assumed all the characters which mark the tropical hurricanes; the wind blowing in sudden gusts and whirlwinds, the lightning and thunder being such as is rarely witnessed in our climate, and heavy rain falling without intermission. The floods extended almost simultaneously, and with equal violence, over that part of the north-east of Scotland which would be cut off by two lines drawn from the head of Lochrannoch, one towards Inverness and the other to Stonehaven. The united line of the different rivers which were flooded could not be less than from five to six hundred miles in length; and the whole of their courses were marked by the destruction of bridges, roads, crops, and buildings. Sir T. D. Lauder has recorded the destruction of thirty-eight bridges, and the entire obliteration of a great number of farms and hamlets. On the Nairn, a fragmant of sandstone, fourteen feet long by three feet wide and one foot thick, was carried above 200 yards down the river. Some new ravines were formed on the sides of mountains where no streams had previously flowed, and ancient river channels, which had never been filled from time immemorial, gave passage to a copious flood.*

The bridge over the Dee at Ballater consisted of five arches, having upon the whole a water-way of 260 feet. The bed of the river, on which the piers rested, was composed of rolled pieces of granite and gneiss. The bridge was built of granite, and had stood uninjured for twenty years; but the different parts were swept away in succession by the flood, and the whole

* Sir T. D. Lauder's Account of the Great Floods in Morayshire, Aug. 1829.

mass of masonry disappeared in the bed of the river. "The river Don," observes Mr. Farquharson, in his account of the inundations, "has upon my own premises forced a mass of four or five hundred tons of stones, many of them two or three hundred pounds' weight, up an inclined plane, rising six feet in eight or ten yards, and left them in a rectangular heap, about three feet deep, on a flat ground; — the heap ends abruptly at its lower extremity." *

The power even of a small rivulet, when swoln by rain, in removing heavy bodies, was lately exemplified (August, 1827,) in the College, a small stream which flows at a moderate declivity from the eastern watershed of the Cheviot Hills. Several thousand tons' weight of gravel and sand were transported to the plain of the Till, and a bridge, then in progress of building, was carried away, some of the arch-stones of which, weighing from half to three quarters of a ton each, were propelled two miles down the rivulet. On the same occasion, the current tore away from the abutment of a mill-dam a large block of greenstone-porphyry, weighing nearly two tons, and transported it to the distance of a quarter of a mile. Instances are related as occurring repeatedly, in which from one to three thousand tons of gravel are, in like manner, removed by this streamlet to still greater distances in one day. †

In the cases above adverted to, the waters of the river and torrent were dammed back by the bridges, which acted as partial barriers, and illustrate the irresistible force of a current when obstructed. Bridges

* Quarterly Journ. of Sci. &c. No. xii. New Series, p. 331.

† See a paper by Mr. Culley, F.G.S. Proceedings of Geol. Soc. No. 12. 1829.

are also liable to be destroyed by the tendency of rivers to shift their course, whereby the pier, or the rock on which the foundation stands, is undermined.

Excavation of rocks by running water.—The rapidity with which even the smallest streams hollow out deep channels in soft and destructible soils is remarkably exemplified in volcanic countries, where the sand and half-consolidated tuffs oppose but a slight resistance to the torrents which descend the mountain side. After the heavy rains which followed the eruption of Vesuvius in 1824, the water flowing from the Atrio del Cavallo cut, in three days, a new chasm through strata of tuff and ejected volcanic matter, to the depth of twenty-five feet. I found the old mule-road, in 1828, intersected by this new ravine.

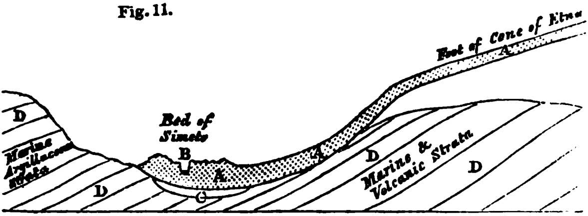
The gradual erosion of deep chasms through some of the hardest rocks, by the constant passage of running water, charged with foreign matter, is another phenomenon of which striking examples may be adduced. Illustrations of this excavating power are presented by many valleys in central France, where the channels of rivers have been barred up by solid currents of lava, through which the streams have re-excavated a passage to the depth of from twenty to seventy feet and upwards, and often of great width. In these cases there are decisive proofs that neither the sea, nor any denuding wave or extraordinary body of water, has passed over the spot since the melted lava was consolidated. Every hypothesis of the intervention of sudden and violent agency is entirely excluded, because the cones of *loose* scoriæ, out of which the lavas flowed, are oftentimes at no great elevation above the rivers, and have remained undis-

turbed during the whole period which has been sufficient for the hollowing out of such enormous ravines.

Recent excavation by the Simeto. — But I shall at present confine myself to examples derived from events which have happened since the time of history.

At the western base of Etna, a current of lava (A A, fig. 11.), descending from near the summit of the great volcano, has flowed to the distance of five or six miles, and then reached the alluvial plain of the

Fig. 11.



Recent excavation of lava at the foot of Etna by the river Simeto.

Simeto, the largest of the Sicilian rivers, which skirts the base of Etna, and falls into the sea a few miles south of Catania. The lava entered the river about three miles above the town of Aderno, and not only occupied its channel for some distance, but, crossing to the opposite side of the valley, accumulated there in a rocky mass. Gemmellaro gives the year 1603 as the date of the eruption.* The appearance of the current clearly proves that it is one of the most modern of those of Etna: for it has not been covered or crossed by subsequent streams or ejections, and the olives which have been planted on its surface are all

* Quadro Istorico dell' Etna, 1824. Some doubts are entertained as to the exact date of this current by others, but all agree that it is not one of the older streams even of the historical era.

of small size, yet older than the natural wood on the same lava. In the course, therefore, of about two centuries, the Simeto has eroded a passage from fifty to several hundred feet wide, and in some parts from forty to fifty feet deep.

The portion of lava cut through is in no part porous or scoriaceous, but consists of a compact homogeneous mass of hard blue rock, somewhat inferior in weight to ordinary basalt, and containing crystals of olivine and glassy felspar. The general declivity of this part of the bed of the Simeto is not considerable; but, in consequence of the unequal waste of the lava, two waterfalls occur at Passo Manzanelli, each about six feet in height. Here the chasm (B, fig. 11.) is about forty feet deep, and only fifty broad.

The sand and pebbles in the river-bed consist chiefly of a brown quartzose sandstone, derived from the upper country; but the materials of the volcanic rock itself must have greatly assisted the attrition. This river, like the Caltabiano on the eastern side of Etna, has not yet cut down to the ancient bed of which it was dispossessed, and of which the probable position is indicated in the annexed diagram (C, fig. 11.).

On entering the narrow ravine where the water foams down the two cataracts, we are entirely shut out from all view of the surrounding country; and a geologist who is accustomed to associate the characteristic features of the landscape with the relative age of certain rocks, can scarcely dissuade himself from the belief that he is contemplating a scene in some rocky gorge of a primary district. The external forms of the hard blue lava are as massive as any of the most ancient trap-rocks of Scotland. The solid surface is in

some parts smoothed and almost polished by attrition, and covered in others with a white lichen, which imparts to it an air of extreme antiquity, so as greatly to heighten the delusion. But the moment we re-ascend the cliff the spell is broken: for we scarcely recede a few paces, before the ravine and river disappear, and we stand on the black and rugged surface of a vast current of lava, which seems unbroken, and which we can trace up nearly to the distant summit of that majestic cone which Pindar called "the pillar of heaven," and which still continues to send forth a fleecy wreath of vapour, reminding us that its fires are not extinct, and that it may again give out a rocky stream, wherein other scenes like that now described may present themselves to future observers.

Falls of Niagara. — The falls of Niagara afford a magnificent example of the progressive excavation of a deep valley in solid rock. That river flows from Lake Erie to Lake Ontario, the former lake being 330 feet above the latter, and the distance between them being thirty-two miles. On flowing out of the upper lake, the river is almost on a level with its banks; so that if it should rise perpendicularly eight or ten feet, it would lay under water the adjacent flat country of Upper Canada on the West, and of the State of New York on the East.* The river, where it issues, is about three quarters of a mile in width. Before reaching the Falls, it is propelled with great rapidity, being a mile broad, about twenty-five feet deep, and having a descent of fifty feet in half a mile. An island at the very verge of the cataract divides it into two sheets of water: one of these, called the

* Captain Hall's Travels in North America, vol. i. p. 179.

Horse-shoe Fall, is six hundred yards wide, and 158 feet perpendicular; the other, called the American Falls, is about two hundred yards in width, and 164 feet in height. The breadth of the island is about five hundred yards. This great sheet of water is precipitated over a ledge of hard limestone, in horizontal strata, below which is a somewhat greater thickness of soft shale, which decays and crumbles away more rapidly, so that the calcareous rock forms an overhanging mass, projecting forty feet or more above the hollow space below.

The blasts of wind, charged with spray, which rise out of the pool into which this enormous cascade is projected, strike against the shale beds, so that their disintegration is constant. They also waste away at certain seasons by the expansive action of frost. The superincumbent limestone, being thus left without a foundation, falls from time to time in rocky masses. When these enormous fragments descend, a shock is felt at some distance, accompanied by a noise like a distant clap of thunder. After the river has passed over the falls, its character, observes Captain Hall, is immediately and completely changed. It then runs furiously along the bottom of a deep wall-sided valley, or huge trench, which has been cut into the horizontal strata by the continued action of the stream during the lapse of ages. The bed of the river here is strewed over with huge fragments of rock; the cliffs on both sides are in most places perpendicular, and the ravine is only perceived on approaching the edge of the precipice.*

The waters, which expand at the falls, where they are divided by the island, are contracted again, after

* Hall's Travels in North America, vol. i. pp. 195, 196. 216.

their union, into a stream not more than 160 yards broad. It is remarkable that the water of the pool into which the cataract is precipitated, and that of the narrow channel immediately below, instead of being in a state of tremendous agitation, is so tranquil as to allow a ferry boat to cross with ease, and even to approach within the reach of the spray, without experiencing any unusual motion. Various explanations have been offered of this phenomenon. According to Mr. Gibson the vast body of sea-green water, instead of plunging deep as a solid column would do into the sheet below, is drawn out in its descent of 160 feet into white rolls of attenuated foam. He conceives, therefore, that most of the water falls lightly in the form of spray, and the force of the rest is broken by the debris which lie immediately at the foot of the fall.*

Recession of the Falls. — When the Falls were visited in 1829 by Mr. R. Bakewell, jun., he ascertained from a person who had lived forty years in that part of the country, and had been the first settler there, that during that period the Falls on the Canada side had receded forty or fifty yards, in consequence of the continued removal of the shale, and undermining of the limestone, above described.† As the ravine, therefore, below the Falls has been thus prolonged, and as that part of the chasm which has been the work of the last half century resembles in depth and width the average dimensions of the ravine below ‡, it is natural to in-

* Silliman's American Journal, vol. xxix. p. 206.

† The memoir of Mr. Bakewell contains two very illustrative sketches of the physical geography of the country between Lakes Erie and Ontario, including the Falls. — Loudon's Mag. of Nat. Hist. No. 12. March, 1830.

‡ See Professor Rogers, Silliman's American Journal, vol. xxvii. p. 326.

quire how long this same process may have continued, and where did the retrogression of the cataract commence? The ravine through which the Niagara flows continues for about seven miles below the Falls, the perpendicular banks maintaining throughout their whole length an average elevation of two hundred feet, for the land above declines gently at the same rate as the bed of the river, which falls 104 feet in its course of seven miles.* The table-land, which is almost on a level with Lake Erie, after sloping insensibly for the space above mentioned, comes suddenly to a termination at Queenstown, where on both sides of the river an abrupt slope, like an inland sea-cliff, is seen extending east and west. At this point the river emerges from the ravine into a plain, which continues to the shores of Lake Ontario. Now it has been a very general opinion that the Falls were once at Queenstown, and that they have gradually retrograded from that place to their present position about seven miles distant. For the table-land extending from Queenstown to Lake Erie consists uniformly of the same geological formations as are now exposed to view at the Falls. The upper deposit is a fresh-water formation, consisting chiefly of gravel, containing fragments of limestone and other transported rocks, with a few feet of fine clay below. The fresh-water shells are said to agree in species with those now inhabiting Lake Erie. Below this superficial covering is rock of hard limestone, about ninety feet in thickness, stretching nearly in a horizontal direction over the whole country, and forming the bed of the river above the Falls, as do the inferior shales below.

* See Professor Rogers, Silliman's American Journal, vol. xxvii. p. 328.

If the recession of the Falls had always proceeded at the rate of about fifty yards in forty years, it would have required, says Mr. Bakewell, nearly ten thousand years for the excavation of the whole ravine, seven miles in length; but Professor Rogers, Mr. Hayes, and other American writers have justly observed, that our calculations of the time employed in the excavation of the ravine must always be extremely uncertain while we remain ignorant of the exact topographical features of the district when it first emerged from the waters, whether of a lake or sea. Part of the ravine may have coincided originally with some rent in the rocks, afterwards enlarged by tides and currents during the gradual upheaval of the country, and before the existence of the river. Mr. Hayes states that between the Falls and Queenstown there is in one place a short lateral indentation, branching off from the principal ravine, which the cataract could not have shaped out, and which therefore implies the former agency of other causes. *

It seems equally difficult to speculate on the future rate of recession of the Falls, for as they retreat the height of the precipice may be reduced or augmented by the varying hardness of the rocks, the division of the stream by islands, and other modifying circumstances.

If in the course of many thousand years the Falls should reach Lake Erie, twenty-five miles distant, that lake might be effectually drained, inasmuch as the present height of the Falls far exceeds the greatest depth of the lake. It has been supposed that in this case the sudden escape of the water might occasion a deluge on the low lands bordering Ontario; but in reply, Mr.

* Silliman's American Journal, vol. xxxv. p. 102.

De la Beche has objected, that as the bottom of Lake Erie shelves verygently from the shore, the discharge, even after the cataract had receded to the lake, would take place gradually, and it would require time before the river channel was cut back to where the water is deepest.*

It may also be questioned whether the entire area of Lake Erie may not be converted into dry land before the Falls recede to its shores, so shallow is this lake, its average depth being only ten or twelve fathoms, and so fast is it filling up with sediment.

* De la Beche, Geol. Manual, 3d edit. p. 60. Rogers, Silliman's American Journal, vol. xxvii. p. 332.

CHAPTER II.

ACTION OF RUNNING WATER — *continued.*

Course of the Po — Desertion of its old channel — Artificial embankments of the Po, Adige, and other Italian rivers — Basin of the Mississippi — Its meanders — Islands — Shifting of its course — Raft of the Atchafalaya — Drift wood — New formed lakes in Louisiana — Earthquakes in valley of Mississippi — Floods caused by land-slips in the White Mountains — Bursting of a lake in Switzerland — Devastations caused by the Anio at Tivoli.

Course of the Po. — THE Po affords an instructive example of the manner in which a great river bears down to the sea the matter poured into it by a multitude of tributaries descending from lofty chains of mountains. The changes gradually effected in the great plain of Northern Italy, since the time of the Roman republic, are considerable. Extensive lakes and marshes have been gradually filled up, as those near Placentia, Parma, and Cremona, and many have been drained naturally by the deepening of the beds of rivers. Deserted river-courses are not unfrequent, as that of the Serio Morto, which formerly fell into the Adda, in Lombardy; and the Po itself has often deviated from its course. Subsequently to the year 1390, it deserted part of the territory of Cremona, and invaded that of Parma; its old channel being still recognizable, and bearing the name of Po Morto. Bressello is one of the towns of which the site was formerly on the left of the Po, but which is now on

the right bank. There is also an old channel of the Po in the territory of Parma, called Po Vecchio, which was abandoned in the twelfth century, when a great number of towns were destroyed. There are records of parish churches, as those of Vicobellignano, Agojolo, and Martignana, having been pulled down and afterwards rebuilt at a greater distance from the devouring stream. In the fifteenth century the main branch again resumed its deserted channel, and carried away a great island opposite Casalmaggiore. At the end of the same century it abandoned, a second time, the bed called "Po Vecchio," carrying away three streets of Casalmaggiore. The friars in the monastery de' Serviti, took the alarm in 1471, demolished their buildings, and reconstructed them at Fontana, whither they had transported the materials. In like manner, the church of S. Rocco was demolished in 1511. In the seventeenth century also the Po shifted its course for a mile in the same district, causing great devastations.*

Artificial embankments of Italian rivers.—To check these and similar aberrations, a general system of embankment has been adopted; and the Po, Adige, and almost all their tributaries, are now confined between high artificial banks. The increased velocity acquired by streams thus closed in enables them to convey a much larger portion of foreign matter to the sea; and, consequently, the deltas of the Po and Adige have gained far more rapidly on the Adriatic since the practice of embankment became almost universal. But, although more sediment is borne to the sea, part of the sand and mud, which in the natural state of

* Dell' Antico Corso de' Fiumi Po, Oglio, ed Adda, dell' Giovanni Romani. Milan, 1828.

things would be spread out by annual inundations over the plain, now subsides in the bottom of the river-channels; and their capacity being thereby diminished, it is necessary, in order to prevent inundations in the following spring, to extract matter from the bed, and to add it to the banks of the river. Hence it happens that these streams now traverse the plain on the top of high mounds, like the waters of aqueducts, and at Ferrara the surface of the Po has become more elevated than the roofs of the houses.* The magnitude of these barriers is a subject of increasing expense and anxiety, it having been sometimes found necessary to give an additional height of nearly one foot to the banks of the Adige and Po in a single season.

The practice of embankment was adopted on some of the Italian rivers as early as the thirteenth century; and Dante, writing in the beginning of the fourteenth, describes, in the seventh circle of hell, a rivulet of tears separated from a burning sandy desert by embankments "like those which, between Ghent and Bruges, were raised against the ocean, or those which the Paduans had erected along the Brenta to defend their villas on the melting of the Alpine snows."

> Quale i Fiamminghi tra Guzzante e Bruggia,
> Temendo il fiotto che in ver lor s'avventa,
> Fanno lo schermo, perchè il mar si fuggia,
> E quale i Padovan lungo la Brenta,
> Per difender lor ville e lor castelli,
> Anzi che Chiarentana il caldo senta —
>
> *Inferno*, Canto xv.

Basin of the Mississippi.—The hydrographical basin of the Mississippi displays, on the grandest scale, the

* Prony, see Cuvier, Disc. Prélim. p. 146.

action of running water on the surface of a vast continent. This magnificent river rises nearly in the forty-ninth parallel of north latitude, and flows to the Gulf of Mexico in the twenty-ninth — a course, including its meanders, of nearly five thousand miles. It passes from a cold arctic climate, traverses the temperate regions, and discharges its waters into the sea in the region of the olive, the fig, and the sugar-cane.* No river affords a more striking illustration of the law before mentioned, that an augmentation of volume does not occasion a proportional increase of surface, nay, is even sometimes attended with a narrowing of the channel. The Mississippi is half a mile wide at its junction with the Missouri†, the latter being also of equal width; yet the united waters have only, from their confluence to the mouth of the Ohio, a medial width of about three quarters of a mile. The junction of the Ohio seems also to produce no increase, but rather a decrease, of surface.‡ The St. Francis, White, Arkansas, and Red rivers, are also absorbed by the main stream with scarcely any apparent increase of its width; and, on arriving near the sea at New Orleans, it is somewhat less than half a mile wide. Its depth there is very variable, the greatest at high water being 168 feet. The mean rate at which the whole body of water flows is variously estimated. According to some, it does not exceed one mile an hour.§

* Flint's Geography, vol. i. p. 21.

† Flint says (vol. i. p. 140.) that, where the Mississippi receives the Missouri, it is a mile and a half wide, but, according to Captain B. Hall, this is a great mistake. — Travels in North America, vol. iii. p. 328.

‡ Flint's Geography, vol. i. p. 142.

§ Hall's Travels in North America, vol. iii. p. 330., who cites Darby.

The alluvial plain of this great river is bounded on the east and west by great ranges of mountains stretching along their respective oceans. Below the junction of the Ohio, the plain is from thirty to fifty miles broad, and after that point it goes on increasing in width, till the expanse is perhaps three times as great! On the borders of this vast alluvial tract are perpendicular cliffs, or "bluffs," as they are called, sometimes three hundred feet or more in height, composed of limestone and other rocks, and often of alluvium. For a great distance the Mississippi washes the eastern "bluffs;" and below the mouth of the Ohio, never once comes in contact with the western. The waters are thrown to the eastern side, because all the large tributary rivers entering from the west, have filled that side of the great valley with a sloping mass of clay and sand. For this reason, the eastern bluffs are continually undermined, and the Mississippi is slowly but incessantly progressing eastward.*

Curves of the Mississippi. — The river traverses the plain in a meandering course, describing immense and uniform curves. After sweeping round the half of a circle, it is carried in a rapid current diagonally across its own channel, to another curve of the same uniformity upon the opposite shore.† These curves are so regular, that the boatmen and Indians calculate distances by them. Opposite to each of them there is always a sand-bar, answering, in the convexity of its form, to the concavity of "the bend," as it is called.‡ The river, by continually wearing these

* Geograph. Descrip. of the State of Louisiana, by W. Darby, Philadelphia, 1816, p. 102.

† Flint's Geog. vol. i. p. 152.

‡ Ibid.

curves deeper, returns, like many other streams before described, on its own tract, so that a vessel in some places, after sailing for twenty-five or thirty miles, is brought round again to within a mile of the place whence it started. When the waters approach so near to each other, it often happens at high floods that they burst through the small tongue of land, and insulate a portion, rushing through what is called the "cut off" with great velocity. At one spot, called the "grand cut off," vessels now pass from one point to another in half a mile to a distance which it formerly required a voyage of twenty miles to reach.*

Waste of its banks. — After the flood season, when the river subsides within its channel, it acts with destructive force upon the alluvial banks, softened and diluted by the recent overflow. Several acres at a time, thickly covered with wood, are precipitated into the stream; and large portions of the islands formed by the process before described are swept away.

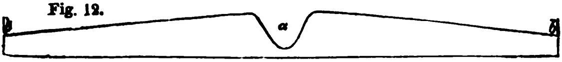
"Some years ago," observes Captain Hall, "when the Mississippi was regularly surveyed, all its islands were numbered, from the confluence of the Missouri to the sea; but every season makes such revolutions, not only in the number but in the magnitude and situation of these islands, that this enumeration is now almost obsolete. Sometimes large islands are entirely melted away — at other places they have attached themselves to the main shore, or, which is the more correct statement, the interval has been filled up by myriads of logs cemented together by mud and rubbish." † When the Mississppi and many

* Flint's Geog. vol. i. p. 154.

† Travels in North America, vol. iii. p. 361.

of its great tributaries overflow their banks, the waters, being no longer borne down by the main current, and becoming impeded amongst the trees and bushes, deposit the sediment of mud and sand with which they are abundantly charged. Islands arrest the progress of floating trees, and they often become in this manner re-united to the land; the rafts of trees, together with mud, constituting at length a solid mass. The coarser and more sandy portion is thrown down first nearest the banks; and finer particles are deposited at the farthest distances from the river, where an impalpable mixture subsides, forming a stiff unctuous black soil. Hence, in the alluvial plains of these rivers the land slopes back, like a natural glacis towards the cliffs bounding the great valley (see fig. 12.), and during

Fig. 12.



a, Channel of the river. *b*, Base of the "bluffs."

inundations the highest part of the banks form narrow strips of dry ground, rising above the river on one side, and above the low flooded country on the other. The Mississippi, therefore, has been described as a river running on the top of a long hill or ridge, which has an elevation of twenty-four feet in its highest part, and a base three miles in average diameter. Flint, however, remarks, that this picture is not very correct, for, notwithstanding the comparative elevation of the banks, the deepest part of the bed of the river (*a*, fig. 12.) is uniformly lower than the lowest point of the alluvium at the base of the bluffs.*

It has been said of a mountain torrent, that "it lays down what it will remove, and removes what it has

* Flint's Geography, vol. i. p. 151.

laid down;" and in like manner the Mississippi, by the continual shifting of its course, sweeps away, during a great portion of the year, considerable tracts of alluvium, which were gradually accumulated by the overflow of former years, and the matter now left during the spring-floods will be at some future time removed.

Rafts.—One of the most interesting features in the great rivers of this part of America is the frequent accumulation of what are termed "rafts," or masses of floating trees, which have been arrested in their progress by snags, islands, shoals, or other obstructions, and made to accumulate, so as to form natural bridges reaching entirely across the stream. One of the largest of these was called the raft of the Atchafalaya, an arm of the Mississippi, which was certainly at some former time the channel of the Red River, when the latter found its way to the Gulf of Mexico by a separate course. The Atchafalaya being in a direct line with the general direction of the Mississippi, catches a large portion of the timber annually brought down from the north; and the drift trees collected in about thirty-eight years previous to 1816 formed a continuous raft, no less than ten miles in length, 220 yards wide, and eight feet deep. The whole rose and fell with the water, yet was covered with green bushes and trees, and its surface enlivened in the autumn by a variety of beautiful flowers. It went on increasing till about 1835, when some of the trees upon it had grown to the height of about sixty feet. Steps were then taken by the state of Louisiana to clear away the whole raft and open the navigation, which was effected, not without great labour, in the space of four years.

The rafts on Red River are equally remarkable; in

some parts of its course, cedar trees are heaped up by themselves, and in other places pines. There is also a raft on the Washita, the principal tributary of the Red River, which seriously interrupts the navigation, concealing the whole river for seventeen leagues. This natural bridge is described in 1804 as supporting all the plants then growing in the neighbouring forest, not excepting large trees; and so perfectly was the stream concealed by the superincumbent mass, that it might be crossed in some places without any knowledge of its existence.*

Drift Wood.—In addition to the astonishing number of cubic feet of timber arrested by the rafts, great deposits are unceasingly in progress at the extremity of the delta in the Bay of Mexico. "Unfortunately for the navigation of the Mississippi," observes Captain Hall, "some of the largest trunks, after being cast down from the position on which they grew, get their roots entangled with the bottom of the river, where they remain anchored, as it were, in the mud. The force of the current naturally gives their tops a tendency downwards, and, by its flowing past, soon strips them of their leaves and branches. These fixtures, called snags or planters, are extremely dangerous to the steam-vessels proceeding up the stream, in which they lie like a lance in rest, concealed beneath the water, with their sharp ends pointed directly against the bow of the vessels coming up. For the most part these formidable snags remain so still, that they can be detected only by a slight ripple above them, not perceptible to inexperienced eyes. Sometimes, however, they vibrate up and down, alternately

* Navigator, p. 263. Pittsburgh, 1821.

showing their heads above the surface, and bathing them beneath it." * So imminent is the danger caused by these obstructions, that almost all the boats on the Mississippi are constructed on a particular plan, to guard against fatal accidents. †

The prodigious quantity of wood annually drifted down by the Mississippi and its tributaries, is a subject of geological interest, not merely as illustrating the manner in which abundance of vegetable matter becomes, in the ordinary course of nature, imbedded in submarine and estuary deposits, but as attesting the constant destruction of soil and transportation of matter to lower levels by the tendency of rivers to shift their courses. Each of these trees must have required many years, some of them centuries, to attain their full size; the soil, therefore, whereon they grew, after remaining undisturbed for long periods, is ultimately torn up and swept away. Yet, notwithstanding this incessant destruction of land and up-rooting of trees, the region which yields this never-failing supply of drift wood is densely clothed with noble forests, and is almost unrivalled in its power of supporting animal and vegetable life.

Innumerable herds of wild deer and bisons feed on the luxurious pastures of the plains. The puma, the

* Travels in North America, vol. iii. p. 362.

† "The boats are fitted," says Captain Hall, "with what is called a snag-chamber; — a partition formed of stout planks, which is caulked, and made so effectually water-tight, that the foremost end of the vessel is cut off as entirely from the rest of the hold as if it belonged to another boat. If the steam-vessel happen to run against a snag, and that a hole is made in her bow, under the surface, this chamber merely fills with water." Travels in North America, vol. iii. p. 363.

wolf, and the fox, are amongst the beasts of prey. The waters teem with alligators and tortoises, and their surface is covered with millions of migratory water-fowl, which perform their annual voyage between the Canadian lakes and the shores of the Mexican Gulf. The power of man begins to be sensibly felt, and the wilderness to be replaced by towns, orchards, and gardens. The gilded steam-boat, like a moving city, now stems the current with a steady pace — now shoots rapidly down the descending stream, through the solitudes of the forests and prairies. Already does the flourishing population of the great valley exceed that of the thirteen United States when first they declared their independence, and, after a sanguinary struggle, were severed from the parent country.* Such is the state of a continent where rocks and trees are hurried annually, by a thousand torrents, from the mountains to the plains, and where sand and finer matter are swept down by a vast current to the sea, together with the wreck of countless forests and the bones of animals which perish in the inundations. When these materials reach the Gulf, they do not render the waters unfit for aquatic animals; but, on the contrary, the ocean here swarms with life, as it generally does where the influx of a great river furnishes a copious supply of organic and mineral matter. Yet many geologists, when they behold the spoils of the land heaped in successive strata, and blended confusedly with the remains of fishes, or interspersed with broken shells and corals, imagine that they are viewing the signs of a turbulent instead of a tranquil and settled state of the planet.

* Flint's Geography, vol. i.

They read in such phenomena the proof of chaotic disorder, and reiterated catastrophes, instead of indications of a surface as habitable as the most delicious and fertile districts now tenanted by man. They are not content with disregarding the analogy of the present course of Nature, when they speculate on the revolutions of past times, but they often draw conclusions, concerning the former state of things, directly the reverse of those to which a fair induction from facts would infallibly lead them.

Formation of lakes in Louisiana.—Another striking feature in the basin of the Mississippi, illustrative of the changes now in progress, is the formation by natural causes of great lakes, and the drainage of others. These are especially frequent in the basin of the Red River in Louisiana, where the largest of them, called Bistineau, is more than *thirty miles* long, and has a medium depth of from *fifteen* to *twenty* feet. In the deepest parts are seen numerous cypress trees, of all sizes, now dead, and most of them with their tops broken by the wind, yet standing erect under water. This tree resists the action of air and water longer than any other, and, if not submerged throughout the whole year, will retain life for an extraordinary period. Lake Bistineau, as well as Black Lake, Cado Lake, Spanish Lake, Natchitoches Lake, and many others, have been formed, according to Darby, by the gradual elevation of the bed of Red River, in which the alluvial accumulations have been so great as to raise its channel, and cause its waters, during the flood season, to flow up the mouths of many tributaries, and to convert parts of their courses into lakes. In the autumn, when the level of Red River is depressed, the waters rush back, and some lakes

become grassy meadows, with streams meandering through them.* Thus, there is a periodical flux and reflux between Red River and some of these basins, which are merely reservoirs, alternately emptied and filled, like our tide estuaries — with this difference, that in the one case the land is submerged for several months continuously, and in the other twice in every twenty-four hours. It has happened, in several cases, that a raft of timber or a bar has been thrown by Red River across some of the openings of these channels, and then the lakes become, like Bistineau, constant repositories of water. But even in these cases, their level is liable to annual elevation and depression, because the flood of the main river, when at its height, passes over the bar; just as, where sand-hills close the entrance of an estuary on the Norfolk or Suffolk coast, the sea, during some high tide or storm, has often breached the barrier and inundated again the interior.

I am informed by Mr. Featherstonhaugh that the plains of the Red River and the Arkansas are so low and flat, that whenever the Mississippi rises thirty feet above its ordinary level, those great tributaries are made to flow back, and inundate a region of vast extent. Both the streams alluded to contain red sediment, derived from the decomposition of red porphyry, and since 1833, when there was a great inundation in the Arkansas, an immense swamp has been formed near the Mammelle mountain, comprising 30,000 acres, with here and there large lagoons where the old bed of the river was situated; in which innumerable trees, for the most part dead, are seen standing, of cypress, cot-

* Darby's Louisiana, p. 33.

ton wood, poplar, the triple thorned acacia, and others, which are of great size. Their trunks appear as if painted red for about fifteen feet from the ground; at which height a perfectly level line extends through the whole forest, marking the rise of the waters during the last flood.*

Perhaps the cause above assigned for the recent origin of these lakes is not the only one. Subterranean movements have altered, so lately as the year 1812, the relative levels of various parts of the basin of the Mississippi, situated about 100 leagues N. E. of Lake Bistineau. In that year the great valley, from the mouth of the Ohio to that of the St. Francis, including a tract 300 miles in length, and exceeding in area the whole basin of the Thames, was convulsed to such a degree, as to create new islands in the river, and lakes in the alluvial plain, some of which were *twenty miles in extent.* Old trees were seen submerged in two of these lakes, called Reelfoot and Obion, about twenty years afterwards.†

Analogous facts have been observed in other parts of N. America. Thus Captains Clark and Lewis found, about the year 1807, a forest of pines standing erect under water in the body of the Columbia river, which they supposed, from the appearance of the trees, to have been submerged only about twenty years.‡ More lately (1835) the Rev. Mr. Parker observed on the same river (lat. 45° N., long. 121° W.) trees standing in their natural position in spots where the water was more than twenty feet deep. The tops of the trees had disappeared, but between high and low

* Featherstonhaugh, Geol. Report, Washington, 1835, p. 84.

† Usher, Silliman's Journal, vol. xxxi. p. 295.

‡ Travels, &c., vol. ii. p. 241.

water mark the trunks were only partially decayed, a fact which proves their submergence to have taken place at a comparatively recent date. The roots were seen through the clear water, spreading as they had grown in their native forest, and from the space which the trees covered it was inferred that a tract of land, more than twenty miles in length and above a mile in width, must have subsided tranquilly.*

FLOODS, BURSTING OF LAKES, ETC.

The power which running water may exert, in the lapse of ages, in widening and deepening a valley, does not so much depend on the volume and velocity of the stream usually flowing in it, as on the number and magnitude of the obstructions which have, at different periods, opposed its free passage. If a torrent, however small, be effectually dammed up, the size of the valley above the barrier, and its declivity below, and not the dimensions of the torrent, will determine the violence of the débâcle. The most universal source of local deluges are landslips, slides, or avalanches, as they are sometimes called, when great masses of rock and soil, or sometimes ice and snow, are precipitated into the bed of a river, the boundary cliffs of which have been thrown down by the shock of an earthquake, or undermined by springs or other causes. Volumes might be filled with the enumeration of instances on record of these terrific catastrophes; I shall therefore select a few examples of recent occurrence, the facts of which are well authenticated.

Floods caused by landslips, 1826.—Two dry seasons in the White Mountains, in New Hampshire, were fol-

* Tour beyond the Rocky Mountains, p. 132.

lowed by heavy rains on the 28th August, 1826, when from the steep and lofty declivities which rise abruptly on both sides of the river Saco, innumerable rocks and stones, many of sufficient size to fill a common apartment, were detached, and in their descent swept down before them, in one promiscuous and frightful ruin, forests, shrubs, and the earth which sustained them. No tradition existed of any similar slides at former times, and the growth of the forest on the flanks of the hills clearly showed that for a long interval nothing similar had occurred. One of these moving masses was afterwards found to have slid three miles, with an average breadth of a quarter of a mile. The natural excavations commenced generally in a trench a few yards in depth and a few rods in width, and descended the mountains, widening and deepening till they became vast chasms. At the base of these hollow ravines was seen a wide and deep mass of ruins, consisting of transported earth, gravel, rocks, and trees. Forests of spruce-fir and hemlock were prostrated with as much ease as if they had been fields of grain; for, where they disputed the ground, the torrent of mud and rock accumulated behind till it gathered sufficient force to burst the temporary barrier.

The valleys of the Amonoosuck and Saco presented, for many miles, an uninterrupted scene of desolation; all the bridges being carried away, as well as those over their tributary streams. In some places, the road was excavated to the depth of from fifteen to twenty feet; in others, it was covered with earth, rocks, and trees, to as great a height. The water flowed for many weeks after the flood, as densely charged with earth as it could be without being changed into mud, and marks were seen in various localities of its having

risen on either side of the valley to more than twenty-five feet above its ordinary level. Many sheep and cattle were swept away, and the Willey family, nine in number, who in alarm had deserted their house, were destroyed on the banks of the Saco; seven of their mangled bodies were afterwards found near the river, buried beneath drift wood and mountain ruins.* Eleven years after the event the deep channels worn by the avalanches of mud and stone, and the immense heaps of boulders and blocks of granite in the river channel, still formed, says Professor Hubbard, a picturesque feature in the scenery.†

But these catastrophes are insignificant, when compared to those which are occasioned by earthquakes, when the boundary hills, for miles in length, are thrown down into the hollow of a valley. I shall have opportunities of alluding to inundations of this kind when treating expressly of earthquakes, and shall content myself at present with selecting an example, of modern date, of a flood caused by the bursting of a temporary lake, the facts having been described, with more than usual accuracy, by scientific observers.

Flood in the valley of Bagnes, 1818.—The valley of Bagnes is one of the largest of the lateral embranchments of the main valley of the Rhone, above the Lake of Geneva. Its upper portion was, in 1818, converted into a lake by the damming up of a narrow pass, by avalanches of snow and ice, precipitated from an elevated glacier into the bed of the river Dranse. In the winter season, during continued frost, scarcely any water flows in the bed of this river to

* Silliman's Journal, vol. xv. No. 2. p. 216. Jan. 1829.

† Ibid. vol. xxxiv. p. 115.

preserve an open channel, so that the ice barrier remained entire until the melting of the snows in spring, when a lake was formed above, about half a league in length, which finally attained in some parts a depth of about two hundred feet, and a width of about seven hundred feet. To prevent or lessen the mischief apprehended from the sudden bursting of the barrier, an artificial gallery, seven hundred feet in length, was cut through the ice, before the waters had risen to a great height. When at length they accumulated and flowed through this tunnel, they dissolved the ice, and thus deepened their channel, until nearly half of the whole contents of the lake were slowly drained off. But at length, on the approach of the hot season, the central portion of the remaining mass of ice gave way with a tremendous crash, and the residue of the lake was emptied in half an hour. In the course of its descent, the waters encountered several narrow gorges, and at each of these they rose to a great height, and then burst with new violence into the next basin, sweeping along rocks, forests, houses, bridges, and cultivated land. For the greater part of its course the flood resembled a moving mass of rock and mud, rather than of water. Some fragments of granitic rocks, of enormous magnitude, and which, from their dimensions, might be compared without exaggeration to houses, were torn out of a more ancient alluvion, and borne down for a quarter of a mile. One of the fragments moved was sixty paces in circumference.* The velocity of the water, in the first part of its course was thirty-three feet per second, which diminished to six feet before it reached

* This block was measured by Capt. B. Hall, R. N.

the Lake of Geneva, where it arrived in six hours and a half, the distance being forty-five miles.*

This flood left behind it, on the plains of Martigny, thousands of trees torn up by the roots, together with the ruins of buildings. Some of the houses in that town were filled with mud up to the second story. After expanding in the plain of Martigny, it entered the Rhone, and did no further damage; but some bodies of men, who had been drowned above Martigny, were afterwards found, at the distance of about thirty miles, floating on the farther side of the Lake of Geneva, near Vevey.

The waters, on escaping from the temporary lake, intermixed with mud and rock, swept along, for the first four miles, at the rate of above twenty miles an hour; and M. Escher, the engineer, calculated that the flood furnished 300,000 cubic feet of water every second — an efflux which is five times greater than that of the Rhine below Basle. Now, if part of the lake had not been gradually drained off, the flood would have been nearly double, approaching in volume to some of the largest rivers in Europe. It is evident, therefore, that, when we are speculating on the excavating force which a river may have exerted in any particular valley, the most important question is, not the volume of the existing stream, nor the present levels of its channel, nor even the nature of the rocks, but the probability of a succession of floods at some period since the time when the valley may have been first elevated above the sea.

For several months after the débâcle of 1818, the

* See an account of the inundation of the Val de Bagnes, in 1818, in Ed. Phil. Journ., vol. i. p. 187., drawn up from the Memoir of M. Escher, with a section, &c.

Dranse, having no settled channel, shifted its position continually from one side to the other of the valley, carrying away newly erected bridges, undermining houses, and continuing to be charged with as large a quantity of earthy matter as the fluid could hold in suspension. I visited this valley four months after the flood, and was witness to the sweeping away of a bridge, and the undermining of part of a house. The greater part of the ice-barrier was then standing, presenting vertical cliffs 150 feet high, like ravines in the lava-currents of Etna or Auvergne, where they are intersected by rivers.

Inundations, precisely similar, are recorded to have occurred at former periods in this district, and from the same cause. In 1595, for example, a lake burst, and the waters, descending with irresistible fury, destroyed the town of Martigny, where from sixty to eighty persons perished. In a similar flood, fifty years before, 140 persons were drowned.

Flood at Tivoli, 1826. — I shall conclude with one more example, derived from a land of classic recollections, the ancient Tibur, and which, like all the other inundations above alluded to, occurred within the present century. The younger Pliny, it will be remembered, describes a flood on the Anio, which destroyed woods, rocks, and houses, with the most sumptuous villas and works of art.* For four or five centuries consecutively, this "headlong stream," as Horace truly called it, has often remained within its bounds, and then, after so long an interval of rest, has at different periods inundated its banks again, and widened its channel. The last of these catastrophes happened 15th Nov. 1826, after heavy rains, such as produced

* Lib. viii. Epist. 17.

the floods before alluded to in Scotland. The waters appear also to have been impeded by an artificial dike, by which they were separated into two parts, a short distance above Tivoli. They broke through this dike; and, leaving the left trench dry, precipitated themselves, with their whole weight, on the right side. Here they undermined, in the course of a few hours, a high cliff, and widened the river's channel about fifteen paces. On this height stood the church of St. Lucia, and about thirty-six houses of the town of Tivoli, which were all carried away, presenting, as they sank into the roaring flood, a terrific scene of destruction to the spectators on the opposite bank. As the foundations were gradually removed, each building, some of them edifices of considerable height, was first traversed with numerous rents, which soon widened into large fissures, until at length the roofs fell in with a crash, and then the walls sank into the river, and were hurled down the cataract below.*

The destroying agency of the flood came within two hundred yards of the precipice on which the beautiful temple of Vesta stands; but fortunately this precious relic of antiquity was spared, while the wreck of modern structures was hurled down the abyss. Vesta, it will be remembered, in the heathen mythology, personified the stability of the earth; and when the Samian astronomer, Aristarchus, first taught that the earth revolved on its axis, and round the sun, he was publicly accused of impiety, "for moving the everlasting Vesta from her place." Playfair observed, that when Hutton ascribed instability to the earth's

* When at Tivoli, in 1829, I received this account from eye-witnesses of the event.

surface, and represented the continents which we inhabit as the theatre of incessant change and movement, his antagonists, who regarded them as unalterable, assailed him in a similar manner with accusations founded on religious prejudices.* We might appeal to the excavating power of the Anio as corroborative of one of the most controverted parts of the Huttonian theory; and if the days of omens had not gone by, the geologists who now worship Vesta might regard the late catastrophe as portentous. We may, at least, recommend the modern votaries of the goddess to lose no time in making a pilgrimage to her shrine, for the next flood may not respect the temple.

* Illustr. of Hutt. Theory, § 3. p. 147.

CHAPTER III.

TRANSPORTATION OF SOLID MATTER BY ICE.

Carrying power of river-ice — Rocks annually conveyed into the St. Lawrence by its tributaries — Effects of the rise of the tide in the estuary of the St. Lawrence — Ground-ice; its origin and transporting power — Glaciers — Theory of their downward movement — The moraine unstratified — Icebergs covered with mud and stones — Limits of glaciers and icebergs — Their effects on the bottom when they run aground — Packing of coast ice — Boulders drifted by ice on coast of Labrador — Blocks moved by ice in the Baltic — Submarine erratics laid dry by upheaval.

THE power of running-water to carry sand, gravel, and fragments of rock to considerable distances is greatly augmented in those regions where, during some part of the year, the frost is of sufficient intensity to convert the water, either at the surface or bottom of rivers, into ice.

This subject may be considered under three different heads: — first, the effect of surface-ice and ground-ice in enabling streams to remove gravel and stones to a distance; secondly, the action of glaciers in the transport of boulders, and in the polishing and scratching of rocks; thirdly, the floating off of glaciers charged with solid matter into the sea, and the drifting of icebergs and coast-ice.

River-ice. — Pebbles and small pieces of rock may be seen entangled in ice, and floating annually down

the Tay in Scotland, as far as the mouth of that river. Similar observations might doubtless be made respecting almost all the larger rivers of England and Scotland, but there seems reason to suspect that the principal transfer from place to place of pebbles and stones adhering to ice goes on unseen by us under water. For although the specific gravity of the compound mass may cause it to sink, it may still be very buoyant, and easily borne along by a feeble current. The ice, moreover, melts very slowly at the bottom of running streams in winter, as the water there is often nearly at the freezing point, as will be seen from what will be said in the sequel of ground-ice.

As we traverse Europe in the latitudes of Great Britain, we find the winters more severe, and the rivers more regularly frozen over. M. Lariviere relates that, being at Memel on the Baltic in 1821, when the ice of the river Niemen broke up, he saw a mass of ice thirty feet long which had descended the stream, and had been thrown ashore. In the middle of it was a triangular piece of granite, about a yard in diameter, resembling in composition the red granite of Finland.*

When rivers in the northern hemisphere flow from south to north, the ice first breaks up in the higher part of their course, and the flooded waters, bearing along large icy fragments, often arrive at parts of the stream which are still firmly frozen over. Great inundations are thus frequently occasioned by the obstructions thrown in the way of the descending waters, as was before noticed when I spoke of the Mackenzie in North America, and the Irtish, Oby, Yenesei, Lena, and other rivers of Siberia. (See p. 150.) A partial

* Consid. sur les Blocs Errat. 1829.

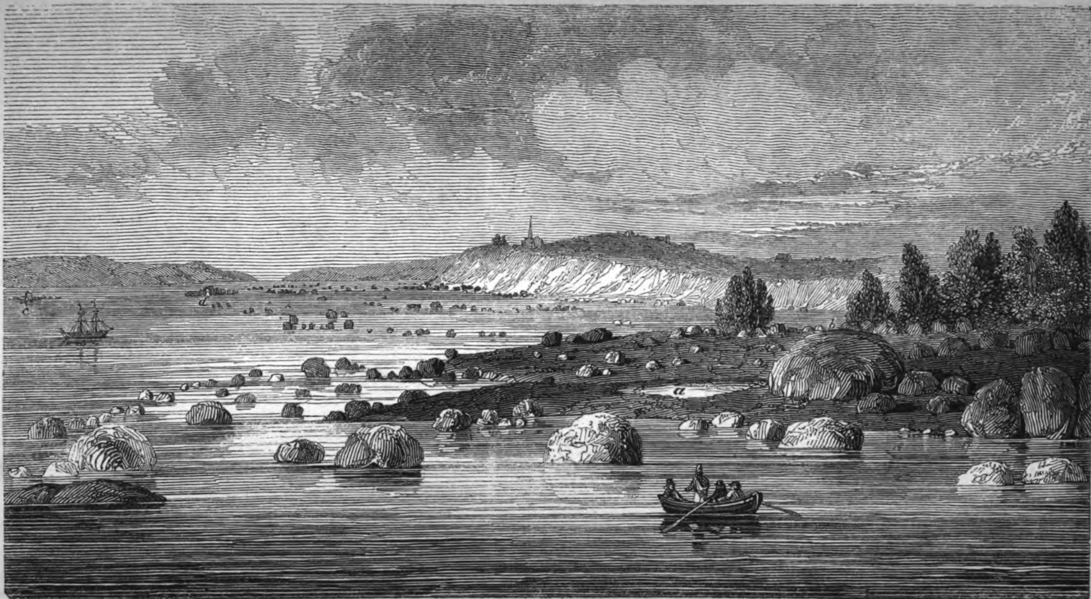
stoppage of this kind lately occurred (Jan. 31. 1840) in the Vistula, about a mile and a half above the city of Dantzic, where the river, choked up by packed ice, was made to take a new course over its right bank, so that it hollowed out in a few days a deep and broad channel, many leagues in length, through a tract of sand hills which were from 40 to 60 feet high.

In Canada, where the winter's cold is intense, in a latitude corresponding to that of central France, several tributaries of the St. Lawrence begin to thaw in their upper course, while they remain frozen over lower down, and thus large slabs of ice are set free and thrown upon the unbroken sheet of ice below. Then begins what is called the packing of the drifted fragments, that is to say, one slab is made to slide over another, until a vast pile is built up, and the whole being frozen together, is urged onwards by the force of the dammed up waters and drift ice. Thus propelled, it not only forces along boulders, but breaks off from cliffs, which border the rivers, huge pieces of projecting rock. By this means several buttresses of solid masonry, which, up to the year 1836, supported a wooden bridge on the St. Maurice, which falls into the St. Lawrence, near the town of Trois Rivières, lat. 46° 20′, were thrown down, and conveyed by the ice into the main river; and instances have occurred at Montreal of wharfs and stone-buildings, from 30 to 50 feet square, having been removed in a similar manner. We learn from Captain Bayfield that anchors laid down within high-water mark, to secure vessels hauled on shore for the winter, must be cut out of the ice on the approach of spring, or they would be carried away. In 1834, the Gulnare's bower anchor, weighing half a ton, was transported some yards by

the ice, and so firmly was it fixed, that the force of the moving ice broke a chain-cable suited for a 10-gun brig, and which had rode the Gulnare during the heaviest gales in the Gulf. Had not this anchor been cut out of the ice, it would have been carried into deep water and lost.*

The scene represented in the annexed plate (pl. 4.), from a drawing by Lieutenant Bowen, R.N., will enable the reader to comprehend the incessant changes which the transport of boulders produces annually on the low islands, shores, and bed of the St. Lawrence above Quebec. The fundamental rocks at Richelieu Rapid, situated in lat. 46° N., are limestone and slate, which are seen at low water to be covered with boulders of granite. These boulders owe their spheroidal form chiefly to weathering, or the action of frost, which causes the surface to exfoliate in concentric plates, so that all the more prominent angles are removed. At the point *a* is a cavity in the mud or sand of the beach, now filled with water, which was occupied during the preceding winter (1835) by the huge erratic *b*, a mass of granite, 70 tons' weight, found in the spring following (1836) at the distance of several feet from its former position. Many small islands are seen on the river, such as *c d*, which afford still more striking proofs of the carrying and propelling power of ice. These islets are never under water, yet every winter ice is thrown upon them in such abundance, that it *packs* to the height of 20, and even 30 feet, bringing with it a continual supply of large stones or boulders, and carrying away others; the greatest number being deposited, according to Lieutenant

* Capt. Bayfield, Geol. Soc. Proceedings, vol. ii. p. 223.



BOULDERS DRIFTED BY ICE ON SHORES OF THE ST. LAWRENCE.

Bowen, on the edge of deep water. On the island *d*, on the left of the accompanying view, a lighthouse is represented, consisting of a square wooden building, which having no other foundation than the boulders, requires to be taken down every winter, and rebuilt on the re-opening of the river.

These effects of frost, which are so striking on the St. Lawrence above Quebec, are by no means displayed on a smaller scale below that city, where the gulf rises and falls with the tide. On the contrary, it is in the estuary, between the latitudes 47° and 49°, that the greatest quantity of gravel and boulders of large dimensions are carried down annually towards the sea. Here the frost is so intense, that a dense sheet of ice is formed at low water, which, on the rise of the tide, is lifted up, broken, and thrown in heaps on the extensive shoals which border the estuary. When the tide recedes, this packed ice is exposed to a temperature sometimes 30° below zero, which freezes together all the loose pieces of ice, as well as the granitic and other boulders. The whole of these are often swept away by a high tide, or when the river is swollen by the melting of the snow in spring. One huge block of granite, 15 feet long by 10 feet both in width and height, and estimated to contain 1500 cubic feet, was conveyed in this manner to some distance in the year 1837, its previous position being well known, as up to that time it had been used by Captain Bayfield as a mark for the surveying station.

Ground-ice. — When a current of cold air passes over the surface of a lake or stream it abstracts from it a quantity of heat, and the specific gravity of the water being thereby increased, the cooled portion sinks. This circulation may continue until the whole body of

fluid has been cooled down to the temperature of 40° F., after which, if the cold increase, the vertical movement ceases, the water which is uppermost expands and floats over the heavier fluid below, and when it has attained a temperature of 32° Fahr. it sets into a sheet of ice. It should seem therefore impossible, according to this law of congelation, that ice should ever form at the bottom of a river; and yet such is the fact, and many speculations have been hazarded to account for so singular a phenomenon. M. Arago is of opinion that the mechanical action of a running stream produces a circulation by which the entire body of water is mixed up together and cooled alike, and the whole being thus reduced to the freezing point, ice begins to form at the bottom for two reasons, first, because there is less motion there, and secondly, because the water is in contact with solid rock or pebbles which have a cold surface.* Whatever explanation we adopt, there is no doubt of the fact, that in countries where the intensity and duration of the cold is great, rivers and torrents acquire an increase of carrying power by the formation of what is called ground-ice. Even in the Thames we learn from Dr. Plott that pieces of this kind of ice, having gravel frozen on to their under side, rise up from the bottom in winter, and float on the surface. In the Siberian rivers, Weitz describes large stones as having been brought up from the river's bed in the same manner, and made to float.†

Glaciers. — In the valleys of all countries bordering the polar circles, and in the higher mountains in temperate latitudes, the snow accumulates in winter, and

* M. Arago, Annuaire, &c. 1833; and Rev. J. Farquharson, Phil. Trans. 1835, p. 329.

† Journ. of Roy. Geograph. Soc. vol. vi. p. 416.

being afterwards partially converted into ice, constitutes what are called glaciers. These in the arctic and antarctic regions descend the valleys gradually till they reach the ocean, where they are floated off in the shape of icebergs, but in lower latitudes, as in the Alps, they descend far below the level of perpetual snow, and there melting, give rise to torrents.

"It has been a generally received opinion," says M. Agassiz, "from the time of Saussure, that the downward movement of a glacier is nothing more than a slipping upon itself occasioned by its own weight; but there are many reasons for doubting the accuracy of this explanation. The motion appears to be much more properly ascribed to the expansion of the ice resulting from the congelation of the water which has filtered into it and penetrated its cavities, for the mass of each glacier is traversed by innumerable fissures which descend to various depths, and are in great part filled with rain water, together with that produced by the melting of the surface-ice. This water being always extremely cold, is made to freeze by the least sinking of the temperature, and tends to dilate the glacier in every direction; but as the mass of ice is restrained on two sides by the flanks of the valley, and on a third by the weight of the ice above, the whole act of dilatation, aided by that of gravitation, tends to urge the glacier down the declivity, or to the only side which offers a free passage." *

But Mr. R. Mallet, in a late memoir on this subject, ascribes the progressive movement of glaciers, which sometimes advance in the Alps as much as twenty-five feet in a year, to the hydrostatic pressure of the

* Agassiz, Jamieson's Ed. New Phil. Journ., No. liv. p. 383.

water which flows at the bottom, and fills rents in the mass. If any obstruction, such as the falling in of ice, stop for a time the free passage of the water flowing below, the accumulated fluid would rend and lift up huge masses, as happened in the winter of 1814-15. At that period the Arveron, a torrent flowing at the bottom of the Mer de Glace, was partly frozen, and partly dammed up by falling masses of ice, so that it could no longer discharge itself at its usual opening, that green arch in which its icy tunnel terminates. The water accumulated, therefore, until it forced itself a new opening 700 feet above the former one, the pressure being so great that for several months huge fragments of ice were precipitated from the glacier.*

Those parts of the Swiss Alps which are more than 8000 feet high are covered with perpetual snow, but the glaciers in the valley of Chamouni descend 4000 feet below this limit, or no less than 12,000 feet below the summit of Mont Blanc: where they reach a district about 3000 feet above the level of the sea in lat. 46°. There they appear, in the heat of summer, in the midst of green forests, and luxuriant pastures, assuming the most fantastic and picturesque shapes, and often terminating upwards in numerous peaks and pinnacles of white ice. According to Saussure, their mean vertical thickness is from 80 to 100 feet, but it amounts in some chasms even to 600 feet.†

The surface of the moving glacier is loaded with sand and large stones derived from boundary rocks, which are precipitous, and occasionally overhanging, and of which pieces are detached by frost or ava-

* Mallet, Seventh Report of Brit. Assoc. p. 64. 1837.

† Voy. dans les Alpes, tom. i. p. 440.

lanches, or broken off by the friction of the moving ice itself, or washed down by torrents. Such materials are generally arranged in long ridges or mounds, sometimes thirty or forty feet high. They are often two, three, or even more in number, like so many lines of intrenchment, and consist of the debris which have been brought in by lateral glaciers. The whole accumulation is called in Switzerland "the moraine," which is slowly conveyed to inferior valleys, and left, where the snow and ice melt, upon the plain. All sand and fragments of soft stone which fall through fissures and reach the bottom of the glaciers, or which are interposed between the glacier and the steep sides of the valley, are pushed along and ground into mud, while the larger and harder fragments have their angles worn off. The fundamental and boundary rocks are also smoothed and polished, and often scored with parallel furrows, or with lines and scratches produced by hard minerals, such as crystals of quartz, which act like the diamond upon glass.*

The moraine of the glacier, observes Charpentier, is entirely devoid of stratification, for there has been no sorting of the materials, as in the case of sand, mud, and pebbles, when deposited by running water. The ice transports indifferently, and to the same spots, the heaviest blocks and the finest particles, mingling all together, and leaving them in one confused and promiscuous heap wherever it melts.†

Icebergs.—In countries situated in high northern latitudes, like Spitzbergen, between 70° and 80° N.,

* Agassiz, Jam. Ed. New Phil. Journ. No. liv. p. 388.

† Charpentier, Ann. des Mines, tom. viii.; see also Papers by MM. Venetz and Agassiz.

glaciers, loaded with mud and rock, descend to the sea, and there huge fragments of them float off and become icebergs. Scoresby counted 500 of these bergs drifting along in latitudes 69° and 70° N., which rose above the surface from the height of 100 to 200 feet, and measured from a few yards to a mile in circumference.* Many of them were loaded with beds of earth and rock of such thickness, that the weight was conjectured to be from 50,000 to 100,000 tons. Specimens of the rocks were obtained, and among them were granite, gneiss, mica-schist, clay-slate, granular felspar, and greenstone. Such bergs must be of great magnitude; because the mass of ice below the level of the water is about eight times greater than that above. Wherever they are dissolved, it is evident that the "moraine" will fall to the bottom of the sea. In this manner may submarine valleys, mountains, and platforms become strewed over with gravel, sand, mud, and scattered blocks of foreign rock, of a nature perfectly dissimilar from all in the vicinity, and which may have been transported across unfathomable abysses. If the bergs happen to melt in still water, so that the earthy and stony materials may fall tranquilly to the bottom, the deposit will probably be unstratified, like the terminal moraine of a glacier; but whenever the materials are under the influence of a current of water as they fall, they will be sorted and arranged according to their relative weight and size, and therefore more or less perfectly stratified.

In a former chapter it was stated, that some ice islands have been known to drift from Baffin's Bay to

* Voyage in 1822, p. 233.

the *Azores*, and from the South Pole to the immediate neighbourhood of the Cape of Good Hope, so that the area over which the effects of moving ice may be experienced, comprehends a large portion of the globe.

We learn from Von Buch that the most southern point on the continent of Europe at which a glacier comes down to the sea is in Norway, in lat. 67° N.* But Mr. Darwin has shown, that they extend to the sea, in South America, in latitudes more than 20° nearer the equator than in Europe; as for example in Chili, where, in the Gulf of Penas, lat. 46° 40′ S., or the latitude of central France; and in Sir George Eyre's Sound, in the latitude of Paris, they give origin to icebergs, which were seen in 1834 carrying angular pieces of granite, and stranding them in fiords, where the shores were composed of clay-slate.† In the island of Georgia, in lat. 54° S., where the perpetual snow descends to the sea-coast, glaciers have been observed to generate icebergs covered with mud and stones.

In a late voyage of discovery made in the antarctic regions in 1839, a dark-coloured angular mass of rock was seen imbedded in an iceberg, drifting along in mid ocean in lat. 61° S. That part of the rock which was visible was about 12 feet in height, and from 5 to 6 in width, but the dark colour of the surrounding ice indicated that much more of the stone was concealed. A sketch made by Mr. Macnab, when the vessel was within a quarter of a mile of it, is now published.‡ This iceberg, one of many observed at sea on the same

* Travels in Norway. † Darwin's Journal, p. 283.

‡ Journ. of Roy. Geograph. Soc., vol. ix. p. 526.

day, was between 250 and 300 feet high, and was no less than 1400 miles from any certainly known land. It is exceedingly improbable, says Mr. Darwin, in his notice on this phenomenon, that any land will hereafter be discovered within 100 miles of the spot, and it must be remembered that the erratic was still firmly fixed in ice, and may have sailed for many a league farther before it dropped to the bottom.*

In the account given by Messrs. Dease and Simpson, of their recent arctic discoveries, we learn that in lat. 71° N., long. 156° W., they found "a long low spit, named Point Barrow, composed of gravel and coarse sand, in some parts more than a quarter of a mile broad, which the pressure of the ice had forced up into numerous mounds, that, viewed from a distance, assumed the appearance of huge boulder rocks." †

This fact is important, as showing how masses of drift ice, when stranding on submarine banks, may exert a lateral pressure capable of bending and dislocating any yielding strata of gravel, sand, or mud. The banks on which icebergs occasionally run aground between Baffin's Bay and Newfoundland, are many hundred feet under water, and the force with which they are struck will depend not so much on the velocity as the momentum of the floating ice-islands. The same berg is often carried away by a change of wind, and then driven back again upon the same bank, or it is made to rise and fall by the waves of the ocean, so that it may alternately strike the bottom with its whole weight, and then be lifted up again, until it has deranged the superficial beds over

* Journ. of Roy. Geograph. Soc. vol. ix. p. 529.

† Ibid. vol. viii. p. 221.

a wide area. In this manner the geologist may account, perhaps, for the circumstance that in Scandinavia, Scotland, and other countries where erratics are met with, the beds of sand, loam, and gravel are often vertical, bent, and contorted into the most complicated folds, while the underlying strata, although composed of equally pliant materials, are horizontal. There can also be little doubt that icebergs must often break off the peaks and projecting points of submarine mountains, and must grate upon and polish their surface, furrowing or scratching them in precisely the same way as we have seen that glaciers act on the solid rocks over which they are propelled.

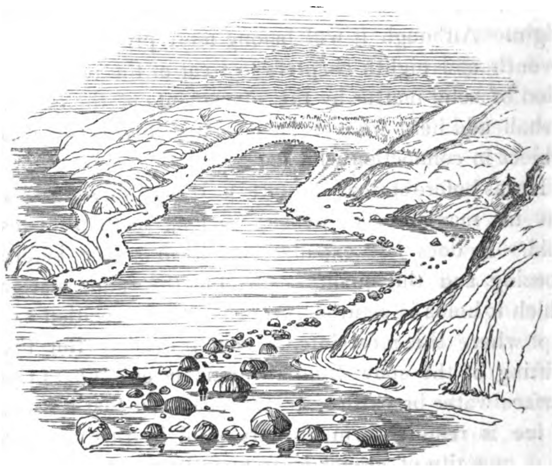
To conclude; it appears that large stones, mud, and gravel, are carried down by the ice of rivers, estuaries, and glaciers, into the sea, where the tides and currents of the ocean, aided by the wind, cause them to drift for hundreds of miles from the place of their origin. Although it will belong more properly to the seventh and eighth chapters to treat of the transportation of solid matter by the movements of the ocean, I shall add here what I have further to say on this subject in connection with ice.

It was before stated (see note, p. 168.) that sea-water has no maximum of density so long as it remains fluid. It does not expand like fresh water before freezing, and this quality, as well as the saline matter which it holds in solution, prevents its congelation except where the most intense cold prevails. But the drifting of the snow from the land often renders the surface water brackish near the coast, so that a sheet of ice is readily formed there, and by this means a large quantity of gravel is frequently conveyed from place to place, and heavy boulders also, when the coast

ice is packed into dense masses. Both the large and small stones thus conveyed, usually travel in one direction like shingle-beaches, and this was observed to take place on the coast of Labrador and Gulf of St. Lawrence, between the latitudes 50° and 60° N., by Capt. Bayfield during his late survey. The line of coast alluded to is strewed over for a distance of 700 miles with ice-borne boulders, often 6 feet in diameter, which are for the most part on their way from north to south, or in the direction of the prevailing current. Some points on this coast have been observed to be occasionally deserted, and then again at another season thickly bestrewed with erratics.

The accompanying drawing (fig. 13.), for which I am indebted to Lieut. Bowen, R.N., represents the

Fig. 13.



Boulders, chiefly of granite, stranded by ice on the coast of Labrador, between lat. 50° and 60° N. (Lieut. Bowen, R. N.)

ordinary appearance of the Labrador coast, between the latitudes of 50° and 60° N. Countless blocks, chiefly granitic, and of various sizes, are seen lying between high and low water mark. Capt. Bayfield saw similar masses carried by ice through the Straits of Belle Isle, between Newfoundland and the American continent, which he conceives may have travelled in the course of years from Baffin's Bay, a distance which may be compared in our hemisphere to the drifting of erratics from Lapland and Iceland as far south as Germany, France, and England.

It may be asked, in what manner have these blocks been originally detached? We may answer that some have fallen from precipitous cliffs, others have been lifted up from the bottom of the sea, adhering by their tops to the ice, while others have been brought down by rivers and glaciers.

The erratics of North America are sometimes angular, but most of them have been rounded either by friction or decomposition. The granite of Canada, as before remarked (p. 372.), has a tendency to concentric exfoliation, and scales off in spheroidal coats when exposed to the spray of the sea during severe frosts. The range of the thermometer in that country usually exceeds, in the course of the year, 100° and sometimes 120° F.; and, to prevent the granite used in the buildings of Quebec from peeling off in winter, it is necessary to oil and paint the squared stones.

In parts of the Baltic, such as the Gulf of Bothnia, where the quantity of salt in the water amounts in general to one fourth only of that in the ocean, the entire surface freezes over in winter to the depth of 5 or 6 feet. Stones are thus frozen in, and afterwards lifted up about 3 feet perpendicularly on the melting of the snow in summer, and then carried by

floating ice-islands to great distances. Professor Von Baer states, in a communication on this subject to the Academy of St. Petersburg, that a block of granite, weighing a million of pounds, was carried by ice during the winter of 1837-8 from Finland to the island of Hochland, and two other huge blocks were transported about the years 1806 and 1814 by packed ice on the south coast of Finland, according to the testimony of the pilots and inhabitants, one block having travelled about a quarter of a mile, and lying about 18 feet above the level of the sea.*

It is well known to all geologists that many enormous masses of gneiss and other rocks are scattered over the low lands bordering the Baltic, which may have been laid dry by that slow upheaval and dessiccation of the bottom of the sea, which is now ascertained to be going on in Sweden and the Gulf of Bothnia. This upward movement may, in the course of ages, have worked so entire a change in the physical geography of these countries, that it is scarcely possible to speculate on the course which drift ice may formerly have taken in northern Europe, unless we are guided by geological data. In those parts of Canada and Labrador where boulders are most frequent on the sea-beach, they are said to be equally numerous in the interior, being seen in as great abundance as the stumps of trees wherever the forests have been partially cleared away. This phenomenon need not be attributed, as some have proposed, to the passage of a flood over the land, but rather to a change of level, like that observed in Scandinavia, which is slowly converting the bed of the ancient ocean, long the receptacle of icebergs, into a part of the American continent.

* Jam. Ed. New Phil. Journ. No. xlviii. p. 439.

CHAPTER IV.

PHENOMENA OF SPRINGS.

Origin of springs — Bored wells — Distinct causes by which mineral and thermal waters may be raised to the surface — Their connection with volcanic agency — Calcareous springs — Travertin of the Elsa — Baths of San Vignone and of San Filippo, near Radicofani — Spheroidal structure in travertin, as in English magnesian limestone — Bulicami of Viterbo — Lake of the Solfatara, near Rome — Travertin at Cascade of Tivoli — Gypseous, siliceous, and ferruginous springs — Brine springs — Carbonated springs — Disintegration of granite in Auvergne — Petroleum springs — Pitch lake of Trinidad.

Origin of springs.— The action of running water on the land having been considered, we may next turn our attention to what may be termed "the subterranean drainage," or the phenomena of springs. Every one is familiar with the fact, that certain porous soils, such as loose sand and gravel, absorb water with rapidity; and that the ground composed of them soon dries up after heavy showers. If a well be sunk in such soils, we often penetrate to considerable depths before we meet with water; but this is usually found on our approaching the lower parts of the formation, where it rests on some impervious bed; for here the water, unable to make its way downwards in a direct line, accumulates as in a reservoir, and is ready to ooze out into any opening which may be made, in the same

manner as we see the salt water flow into, and fill, any hollow which we dig in the sands of the shore at low tide.

The facility with which water can percolate loose and gravelly soils is clearly illustrated by the effect of the tides in the Thames between Richmond and London. The river, in this part of its course, flows through a bed of gravel overlying clay, and the porous superstratum is alternately saturated by the water of the Thames as the tide rises, and then drained again to the distance of several hundred feet from the banks when the tide falls, so that the wells in this tract regularly ebb and flow.

If the transmission of water through a porous medium be so rapid, we cannot be surprised that springs should be thrown out on the side of a hill, where the upper set of strata consist of chalk, sand, or other permeable substances, while the subjacent are composed of clay or other retentive soils. The only difficulty, indeed, is to explain why the water does not ooze out every where along the line of junction of the two formations, so as to form one continuous land-soak, instead of a few springs only, and these far distant from each other. The principal cause of this concentration of the waters at a few points is, first, the frequency of rents and fissures, which act as natural drains; secondly, the existence of inequalities in the upper surface of the impermeable stratum, which lead the water, as valleys do on the external surface of a country, into certain low levels and channels.

That the generality of springs owe their supply to the atmosphere is evident from this, that they become languid, or entirely cease to flow, after long droughts, and are again replenished after a continuance of rain.

Many of them are probably indebted for the constancy and uniformity of their volume to the great extent of the subterranean reservoirs with which they communicate, and the time required for these to empty themselves by percolation. Such a gradual and regulated discharge is exhibited, though in a less perfect degree, in every great lake which is not sensibly affected in its level by sudden showers, but only slightly raised; so that its channel of efflux, instead of being swollen suddenly like the bed of a torrent, is enabled to carry off the surplus water gradually.

Much light has been thrown, of late years, on the theory of springs, by the boring of what are called by the French "Artesian wells," because the method has long been known and practised in Artois; and it is now demonstrated that there are sheets, and, in some places, currents of fresh water, at various depths in the earth. The instrument employed in excavating these wells is a large auger, and the cavity bored is usually from three to four inches in diameter. If a hard rock is met with, it is first triturated by an iron rod, and the materials, being thus reduced to small fragments or powder, are readily extracted. To hinder the sides of the well from falling in, as also to prevent the spreading of the ascending water in the surrounding soil, a jointed pipe is introduced, formed of wood in Artois, but in other countries more commonly of metal. It frequently happens that, after passing through hundreds of feet of retentive soils, a water-bearing stratum is at length pierced, when the fluid immediately ascends to the surface and flows over. The first rush of the water up the tube is often violent, so that for a time the water plays like a fountain, and then, sinking, continues to flow over tranquilly, or sometimes remains sta-

tionary at a certain depth below the orifice of the well. This spouting of the water in the first instance is probably owing to the disengagement of air and carbonic acid gas, for both of these have been seen to bubble up with the water.*

At Sheerness, at the mouth of the Thames, a well was bored on a low tongue of land near the sea, through 300 feet of the blue clay of London, below which a bed of sand and pebbles was entered, belonging, doubtless, to the plastic clay formation: when this stratum was pierced, the water burst up with impetuosity, and filled the well. By another perforation at the same place, the water was found at the depth of 328 feet, below the surface clay; it first rose rapidly to the height of 189 feet, and then, in the course of a few hours, ascended to an elevation of eight feet above the level of the ground. In 1824 a well was dug at Fulham, near the Thames, at the Bishop of London's, to the depth of 317 feet, which, after traversing the tertiary strata, was continued through 67 feet of chalk. The water immediately rose to the surface, and the discharge was above 50 gallons per minute. In the garden of the Horticultural Society at Chiswick, the borings passed through 19 feet of gravel, 242½ feet of clay and loam, and 67½ feet of chalk, and the water then rose to the surface from a depth of 329 feet.† At the Duke of Northumberland's, above Chiswick, the borings were carried to the extraordinary depth of 620 feet, so as to enter the chalk, when a considerable volume of water was obtained, which rose four feet above the surface of the ground. In a well of Mr. Brooks, at

* Consult Héricart de Thury's work on "Puits Forés."

† Sabine, Journ. of Sci. No. xxxiii. p. 72. 1824.

Hammersmith, the rush of water from a depth of 360 feet was so great, as to inundate several buildings and do considerable damage; and at Tooting, a sufficient stream was obtained to turn a wheel, and raise the water to the upper stories of the houses.* In the last of three wells bored through the chalk, at Tours, to the depth of several hundred feet, the water rose 32 feet above the level of the soil, and the discharge amounted to 300 cubic yards of water every twenty-four hours.†

Excavations have been made in the same way to the depth of 800, and even 1200 feet, in France (the latter at Toulouse), and without success.‡ By way of experiment, they are now sinking a well at Paris, the boring of which had reached, in November, 1839, a depth of more than 1600 English feet, and which it is determined to continue to the depth of more than 2000 feet, if overflowing water be not found sooner. It is presumed that the water issuing from so great a depth will possess a temperature of between 93° and 95° F., and the temperature has increased at present at the rate of 1° 8′ F. for 101 English feet. Mr. Briggs, the British consul in Egypt, obtained water between Cairo and Suez, in a calcareous sand, at the depth of thirty feet; but it did not rise in the well.§ But other borings in the same desert, of variable depth, between 50 and 300 feet, and which passed through alternations of sand, clay, and siliceous rock, yielded water at the surface.‖ The geological structure of

* Héricart de Thury, p. 49.

† Bull. de la Soc. Géol. de France, tom. iii. p. 194.

‡ Id. tom. ii. p. 272.

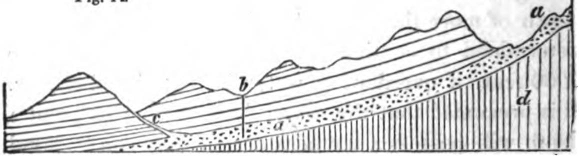
§ Boué, Résumé des Prog. de la Géol. en 1832, p. 184.

‖ Seventh Rep. Brit. Ass. 1837, p. 66.

the Sahara is supposed, by M. Rozet, to favour the prospect of a supply of water from Artesian wells, as the parched sands on the outskirts of the desert rest on a substratum of argillaceous marl. *

The rise and overflow of the water in these wells is generally referred, and apparently with reason, to the same principle as the play of an artificial fountain. Let the porous stratum, or set of strata, *a a*, rest on the impermeable rock *d*, and be covered by another mass of an impermeable nature. The whole mass *a a* may easily, in such a position, become saturated with water, which may descend from its higher and exposed parts — a hilly region to which clouds are attracted,

Fig. 14.



and where rain falls in abundance. Suppose that at some point, as at *b*, an opening be made, which gives a free passage upwards to the waters confined in *a a*, at so low a level that they are subjected to the pressure of a considerable column of water collected in the more elevated portion of the same stratum. The water will then rush out, just as the liquid from a large barrel which is tapped, and it will rise to a height corresponding to the level of its point of departure, or, rather, to a height which balances the pressure previously exerted by the confined waters against the roof and sides of the stratum or reservoir

* Bull. de la Soc. Géol. de France, tom. ii. p. 364.

a a. In like manner, if there happen to be a natural fissure *c*, a spring will be produced at the surface on precisely the same principle.

Among the causes of the failure of Artesian wells, we may mention those numerous rents and faults which abound in some rocks, and the deep ravines and valleys by which many countries are traversed; for, when these natural lines of drainage exist, there remains a small quantity only of water to escape by artificial issues. We are also liable to be baffled by the great thickness either of porous or impervious strata, or by the dip of the beds, which may carry off the waters from adjoining high lands to some trough in an opposite direction, as when the borings are made at the foot of an escarpment where the strata incline inwards, or in a direction opposite to the face of the cliffs.

The mere distance of hills or mountains need not discourage us from making trials; for the waters which fall on these higher lands readily penetrate to great depths through highly inclined or vertical strata, or through the fissures of shattered rocks, and after flowing for a great distance, must often re-ascend and be brought up again by other fissures, so as to approach the surface in the lower country. Here they may be concealed beneath a covering of undisturbed horizontal beds, which it may be necessary to pierce in order to reach them. It should be remembered, that the course of waters flowing under ground bears but a remote resemblance to that of rivers on the surface, there being, in the one case, a constant descent from a higher to a lower level from the source of the stream to the sea; whereas, in the other, the water may at one time

sink far below the level of the ocean, and afterwards rise again high above it.

Among other curious facts ascertained by aid of the borer, it is proved that in strata of different ages and compositions, there are often open passages by which the subterranean waters circulate. Thus at St. Ouen, in France, five distinct sheets of water were intersected in a well, and from each of these a supply obtained. In the third water-bearing stratum, at the depth of 150 feet, a cavity was found in which the borer fell suddenly about a foot, and thence the water ascended in great volume.* The same falling of the instrument, as in a hollow space, has been remarked in England and other countries. At Tours, in 1830, a well was perforated quite through the chalk, when the water suddenly brought up, from a depth of 364 feet, a great quantity of fine sand, with much vegetable matter and shells. Branches of a thorn several inches long, much blackened by their stay in the water, were recognized, as also the stems of marsh plants, and some of their roots, which were still white, together with the seeds of the same, in a state of preservation, which showed that they had not remained more than three or four months in the water. Among the seeds were those of the marsh-plant *Galium uliginosum;* and among the shells, a freshwater species (*Planorbis marginatus*), and some land species, as *Helix rotundata* and *H. striata.* M. Dujardin, who, with others, observed this phenomenon, supposes that the waters had flowed from some valleys of Auvergne or the Vivarais since the preceding autumn. †

* H. de Thury, p. 295.

† Bull. de la Soc. Géol. de France, tom. i. p. 93.

An analogous phenomenon is recorded at Riemke, near Bochum in Westphalia, where the water of an Artesian well brought up, from a depth of 156 feet, several small fish, three or four inches long, the nearest streams in the country being at the distance of some leagues.*

In both cases it is evident that water had penetrated to great depths, not simply by filtering through a porous mass, for then it would have left behind the shells, fish, and fragments of plants, but by flowing through some open channels in the earth. Such examples may suggest the idea that the leaky beds of rivers are often the feeders of springs.

MINERAL AND THERMAL SPRINGS.

Almost all springs, even those which we consider the purest, are impregnated with some foreign ingredients, which, being in a state of chemical solution, are so intimately blended with the water, as not to affect its clearness, while they render it, in general, more agreeable to our taste, and more nutritious than simple rain-water. But the springs called mineral contain an unusual abundance of earthy matter in solution, and the substances with which they are impregnated correspond remarkably with those evolved in a gaseous form by volcanos. Many of these springs are thermal, and they rise up through all kinds of rock; as, for example, through granite, gneiss, limestone, or lava, but are most frequent in volcanic regions, or where violent earthquakes have occurred at eras comparatively modern.

The water given out by hot springs is generally

* Bull. de la Soc. Géol. de France, tom. ii. p. 248

more voluminous and less variable in quantity at different seasons than that proceeding from any others. In many volcanic regions, jets of steam, called by the Italians "stufas," issue from fissures, at a temperature high above the boiling point, as in the neighbourhood of Naples, and in the Lipari Isles, and are disengaged unceasingly for ages. Now, if such columns of steam, which are often mixed with other gases, should be condensed before reaching the surface by coming in contact with strata filled with cold water, they may give rise to thermal and mineral springs of every degree of temperature. It is, indeed, by this means only, and not by hydrostatic pressure, that we can account for the rise of such bodies of water from great depths; nor can we hesitate to admit the adequacy of the cause, if we suppose the expansion of the same elastic fluids to be sufficient to raise columns of lava to the lofty summits of volcanic mountains. Several gases, the carbonic acid in particular, are disengaged in a free state from the soil in many districts, especially in the regions of active or extinct volcanos; and the same are found more or less intimately combined with the waters of all mineral springs, both cold and thermal. Dr. Daubeny and other writers have remarked, not only that these springs are most abundant in volcanic regions, but that when remote from them, their site usually coincides with the position of some great derangement in the strata; a fault, for example, or great fissure, indicating that a channel of communication has been opened with the interior of the earth at some former period of local convulsion. It is also ascertained that at great heights in the Pyrenees and Himalaya mountains hot springs burst out from granitic rocks, and they are abundant in the Alps also,

these chains having all been disturbed and dislocated at times comparatively modern, as can be shown by independent geological evidence.

The small area of volcanic regions may appear, at first view, an objection to some of the views above set forth, but not so when we include earthquakes among the effects of igneous agency. A large proportion of the land hitherto explored by geologists can be shown to have been rent or shaken by subterranean movements since the oldest tertiary strata were formed. It will also be seen, in the sequel, that new springs have burst out, and others have had the volume of their waters augmented, and their temperature suddenly raised after earthquakes, so that the description of these springs might almost with equal propriety have been given under the head of "igneous causes," as they are agents of a mixed nature, being at once igneous and aqueous.

But how, it will be asked, can the regions of volcanic heat send forth such inexhaustible supplies of water? The difficulty of solving this problem would, in truth, be insurmountable, if we believed that all the atmospheric waters found their way into the basin of the ocean; but in boring near the shore, we often meet with streams of fresh water at the depth of several hundred feet below the sea level; and these probably descend, in many cases, far beneath the bottom of the sea, when not artificially intercepted in their course. Yet, how much greater may be the quantity of salt water which sinks beneath the floor of the ocean, through the porous strata of which it is often composed, or through fissures rent in it by earthquakes. After penetrating to a considerable depth, this water may encounter a heat of sufficient intensity to convert

it into vapour, even under the high pressure to which it would then be subjected. This heat would probably be nearest the surface in volcanic countries, and farthest from it in those districts which have been longest free from eruptions or earthquakes; but to pursue this inquiry farther would lead us to anticipate many topics belonging to another division of our subject.

It would follow from the views above explained, that there must be a two-fold circulation of terrestrial waters; one caused by solar heat, and the other by heat generated in the interior of our planet. We know that the land would be unfit for vegetation, if deprived of the waters raised into the atmosphere by the sun; but it is also true that mineral springs are powerful instruments in rendering the surface subservient to the support of animal and vegetable life. Their heat is said to promote the development of the aquatic tribes in many parts of the ocean, and the substances which they carry up from the bowels of the earth to the habitable surface, are of a nature and in a form which adapts them peculiarly for the nutrition of animals and plants.

As these springs derive their chief importance to the geologist from the quantity and quality of the earthy materials which, like volcanos, they convey from below upwards, they may properly be considered in reference to the ingredients which they hold in solution. These consist of a great variety of substances; but the most predominant are, carbonate of lime, carbonic and sulphuric acids, iron, silica, magnesia, alumine, and salt, besides petroleum, or liquid bitumen, and its various modifications, such as mineral pitch, naphtha, and asphaltum.

Calcareous springs.—Our first attention is naturally directed to springs which are highly charged with calcareous matter, for these produce a variety of phenomena of much interest in geology. It is known that rain-water has the property of dissolving the calcareous rocks over which it flows, and thus, in the smallest ponds and rivulets, matter is often supplied for the earthy secretions of testacea, and for the growth of certain plants on which they feed. But many springs hold so much carbonic acid in solution, that they are enabled to dissolve a much larger quantity of calcareous matter than rain-water; and when the acid is dissipated in the atmosphere, the mineral ingredients are thrown down, in the form of tufa or travertin.*

Auvergne.—Calcareous springs, although most abundant in limestone districts, are by no means confined to them, but flow out indiscriminately from all rock formations. In Central France, a district where the primary rocks are unusually destitute of limestone, springs copiously charged with carbonate of lime rise up through the granite and gneiss. Some of these are thermal, and probably derive their origin from the deep source of volcanic heat, once so active in that region. One of these springs, at the northern base of the hill upon which Clermont is built, issues from volcanic peperino, which rests on granite. It has formed, by its incrustations, an elevated mound of travertin, or white concretionary limestone, 240 feet in length, and, at its termination, sixteen feet high and twelve wide. Another incrusting spring in the same department, situated at Chaluzet, near Pont Gibaud, rises in a

* The more loose and porous rock, usually containing incrusted plants and other substances, is called *tufa*; the more compact, *travertin*. See Glossary, 'Tufa,' 'Travertin,' end of Vol. III.

gneiss country, at the foot of a regular volcanic cone, at least twenty miles from any calcareous rock. Some masses of tufaceous deposit, produced by this spring, have an oolitic texture.

Valley of the Elsa.— If we pass from the volcanic district of France to that which skirts the Apennines in the Italian peninsula, we meet with innumerable springs which have precipitated so much calcareous matter, that the whole ground in some parts of Tuscany is coated over with tufa and travertin, and sounds hollow beneath the foot.

In other places in the same country, compact rocks are seen descending the slanting sides of hills, very much in the manner of lava currents, except that they are of a white colour, and terminate abruptly when they reach the course of a river. These consist of a calcareous precipitate from springs, some of which are still flowing, while others have disappeared or changed their position. Such masses are frequent on the slope of the hills which bound the valley of the Elsa, one of the tributaries of the Arno, which flows near Colle, through a valley several hundred feet deep, shaped out of a lacustrine formation, containing fossil shells of existing species. The travertin is unconformable to the lacustrine beds, and its inclination accords with the slope of the sides of the valley.

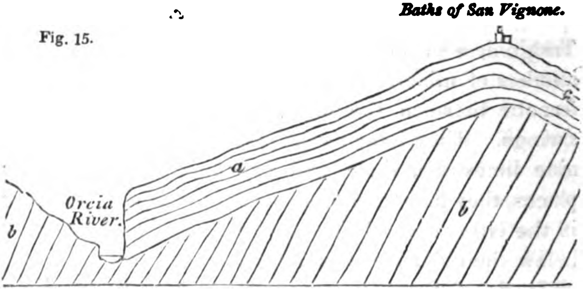
One of the finest examples which I saw, was at the Molino delle Caldane, near Colle.

The Sena, and several other small rivulets which feed the Elsa, have the property of lapidifying wood and herbs; and, in the bed of the Elsa itself, aquatic plants, such as Charæ, which absorb large quantities of carbonate of lime, are very abundant. Carbonic acid is also seen in the same valley, bubbling up from many

springs, where no precipitate of tufa is observable. Targioni, who in his travels has mentioned a great number of mineral waters in Tuscany, found no difference between the deposits of cold and thermal springs. They issue sometimes from the older Apennine limestone, shale, and sandstone, while, in other places, they flow from more modern deposits; but even in the latter case, their source may probably be in or below the older series of strata.

Baths of San Vignone. — Those persons who have merely seen the action of petrifying waters in our own country, will not easily form an adequate conception of the scale on which the same process is exhibited in those regions which lie nearer to the active centres of volcanic disturbance. One of the most striking examples of the rapid precipitation of carbonate of lime from thermal waters occurs in the hill of San Vignone in Tuscany, at a short distance from Radicofani, and only a few hundred yards from the high road between Sienna and Rome. The spring issues from near the summit of a rocky hill, about 100 feet in height. The top of the hill is flat, and stretches in a gently inclined platform to the foot of Mount Amiata, a lofty eminence, which consists in great part of volcanic products. The fundamental rock, from which the spring issues, is a black slate, with serpentine (*b b*, Fig. 15.), belonging to the older Apennine formation. The water is hot, has a strong taste, and, when not in very small quantity, is of a bright green colour. So rapid is the deposition near the source, that in the bottom of a conduit-pipe for carrying off the water to the baths, and which is inclined at an angle of 30°, half a foot of solid travertin is formed every year. A more compact rock is produced where the

Fig. 15.



Section of travertin, San Vignone.

water flows slowly, and the precipitation in winter, when there is least evaporation, is said to be more solid, but less in quantity by one fourth, than in summer. The rock is generally white; some parts of it are compact, and ring to the hammer; others are cellular, and with such cavities as are seen in the carious part of bone or the siliceous millstone of the Paris basin. A portion of it also below the village of San Vignone consists of incrustations of long vegetable tubes, and may be called tufa. Sometimes the travertin assumes precisely the botryoidal and mamillary forms, common to similar deposits in Auvergne, of a much older date; and, like them, it often scales off in thin, slightly undulating layers.

A large mass of travertin (*c*, Fig. 15.) descends the hill from the point where the spring issues, and reaches to the distance of about half a mile east of San Vignone. The beds take the slope of the hill at about an angle of 6°, and the planes of stratification are perfectly parallel. One stratum, composed of many layers, is of a compact nature, and fifteen feet thick: it serves as an excellent building stone, and a mass of

fifteen feet in length was, in 1828, cut out for the new bridge over the Orcia. Another branch of it (*a*, Fig.15.) descends to the west, for 250 feet in length, of varying thickness, but sometimes 200 feet deep : it is then cut off by the small river Orcia, precisely as some glaciers in Switzerland descend into a valley till their progress is suddenly arrested by a transverse stream of water.

The abrupt termination of the mass of rock at the river, when its thickness is undiminished, clearly shows that it would proceed much farther if not arrested by the stream, over which it impends slightly. But it cannot encroach upon the channel of the Orcia, being constantly undermined, so that its solid fragments are seen strewed amongst the alluvial gravel. However enormous, therefore, the mass of solid rock may appear which has been given out by this single spring, we may feel assured that it is insignificant in volume when compared to that which has been carried to the sea since the time when it began to flow. What may have been the length of that period of time we have no data for conjecturing. In quarrying the travertin, Roman tiles have been sometimes found at the depth of five or six feet.

Baths of San Filippo.—On another hill, not many miles from that last mentioned, and also connected with Mount Amiata, the summit of which is about three miles distant, are the celebrated baths of San Filippo. The subjacent rocks consist of alternations of black slate, limestone, and serpentine, of highly inclined strata, belonging to the Apennine formation, and, as at San Vignone, near the boundary of a tertiary basin of marine origin, consisting chiefly of blue argillaceous marl. There are three warm springs here

containing carbonate and sulphate of lime, and sulphate of magnesia. The water which supplies the baths falls into a pond, where it has been known to deposit a solid mass *thirty feet thick*, in about *twenty years.** A manufactory of medallions in basso-relievo is carried on at these baths. The water is conducted by canals into several pits, in which it deposits travertin and crystals of sulphate of lime. After being thus freed from its grosser parts, it is conveyed by a tube to the summit of a small chamber, and made to fall through a space of ten or twelve feet. The current is broken in its descent by numerous crossed sticks, by which the spray is dispersed around upon certain moulds, which are rubbed lightly over with a solution of soap, and a deposition of solid matter like marble is the result, yielding a beautiful cast of the figures formed in the mould.† The geologist may derive from these experiments considerable light, in regard to the high slope of the strata at which some semi-crystalline precipitations can be formed; for some of the moulds are disposed almost perpendicularly, yet the deposition is nearly equal in all parts.

A hard stratum of stone, about a foot in thickness, is obtained from the waters of San Filippo in four months; and, as the springs are powerful, and almost uniform in the quantity given out, we are at no loss to comprehend the magnitude of the mass which descends the hill, which is a mile and a quarter in length and the third of a mile in breadth, in some places attaining a thickness of 250 feet at least. To what length it might have reached it is impossible to con-

* Dr. Grosse on the Baths of San Filippo. Ed. Phil. Journ. vol. ii. p. 292.

† Id. p. 297.

jecture, as it is cut off, like the travertin of San Vignone, by a small stream, where it terminates abruptly. The remainder of the matter held in solution is carried on probably to the sea.

Spheroidal structure in travertin.—But what renders this recent limestone of peculiar interest to the geologist, is the spheroidal form which it assumes, analogous to that of the cascade of Tivoli, afterwards to be described. The lamination of some of the concentric masses is so minute that sixty may be counted in the thickness of an inch, yet, notwithstanding these marks of gradual and successive deposition, sections are sometimes exhibited of what might seem to be perfect spheres. This tendency to a mammillary and globular structure arises from the facility with which the calcareous matter is precipitated in nearly equal quantities on all sides of any fragment of shell or wood, or any inequality of the surface over which the mineral water flows, the form of the nucleus being readily transmitted through any number of successive envelopes. But these masses can never be perfect spheres, although they often appear such when a transverse section is made in any line not in the direction of the point of attachment. There are, indeed, occasionally seen small oolitic and pisolitic grains, of which the form is globular; for the nucleus having been for a time in motion in the water, has received fresh accessions of matter on all sides.

In the same manner I have seen, on the vertical walls of large steam boilers, the heads of nails or rivets covered by a series of enveloping crusts of calcareous matter, usually sulphate of lime; so that a concretionary nodule is formed, preserving a nearly globular shape, when increased to a mass several

inches in diameter. In these, as in many travertins, there is often a combination of the concentric and radiated structure, and the last-mentioned character is one of those in which the English magnesian limestone agrees with the Italian travertins.

Another point of resemblance between these rocks, in other respects so dissimilar, is the interference of one sphere with another, and the occasional occurrence of cavities and vacuities, constituting what has been called a honeycombed structure, and also the frequent interposition of loose incoherent matter, between different solid spheroidal concretions. Yet, notwithstanding such points of analogy, Professor Sedgwick observes, that there are proofs of the concretionary arrangement in the magnesian limestone having taken place subsequently to original deposition, for in this case the spheroidal forms are often quite independent of the direction of the laminæ.*

Bulicami of Viterbo.—I must not attempt to describe all the places in Italy where the constant formation of limestone may be seen, as on the Silaro, near Pæstum, or on the Velino at Terni. But the hot springs in the vicinity of Viterbo, which I visited in 1828, deserve particular notice. Their petrifying powers were recorded by Dante, so long ago as the year 1300.

> "Quale del Bulicame esce'l ruscello."
> "E'en as the rivulet from Bulicame," &c.
>
> *Inf.* xiv. 79.

About a mile and a half north of that town, in the midst of a sterile plain of volcanic sand and ashes, and near the hot baths called the Bulicami, a monticule is

* Geol. Trans. second series, vol. iii. p. 37.

seen, about 20 feet high and 500 yards in circumference, entirely composed of concretionary travertin. This rock has been largely quarried for lime, and much of it appears to have been removed. The laminæ are very thin, and their minute undulations so arranged, that the whole mass has at once a concentric and radiated structure. The beds dip at an angle of 40° or more from the centre of the monticule outwards. The whole mass has evidently been formed gradually, like the conical mounds of the geysers in Iceland, by a small jet or fountain of calcareous water, which overflowed from the summit of the monticule, but which is now dried up. A spring of hot water still issues (1828) in the neighbourhood, which is conveyed to an open tank used as a bath, the bottom and sides of which, as well as the open conduit which conveys the water, are encrusted with travertin.

Campagna di Roma. — The country around Rome, like many parts of the Tuscan States already referred to, has been at some former period the site of numerous volcanic eruptions; and the springs are still copiously impregnated with lime, carbonic acid, and sulphuretted hydrogen. A hot spring was discovered about 1827, near Civita Vecchia, by Signor Riccioli, which deposits alternate beds of a yellowish travertin, and a white granular rock, not distinguishable, in hand specimens, either in grain, colour, or composition, from statuary marble. There is a passage between this and ordinary travertin. The mass accumulated near the spring is in some places about six feet thick.

Lake of the Solfatara. — In the Campagna, between Rome and Tivoli, is the lake of the Solfatara, called also Lago di Zolfo (lacus albula), into which flows continually a stream of tepid water from a smaller lake,

situated a few yards above it. The water is a saturated solution of carbonic acid gas, which escapes from it in such quantities in some parts of its surface, that it has the appearance of being actually in ebullition. "I have found by experiment," says Sir Humphry Davy, "that the water taken from the most tranquil part of the lake, even after being agitated and exposed to the air, contained in solution more than its own volume of carbonic acid gas, with a very small quantity of sulphuretted hydrogen. Its high temperature, which is pretty constant at 80° of Fahr., and the quantity of carbonic acid that it contains, render it peculiarly fitted to afford nourishment to vegetable life. The banks of travertin are every where covered with reeds, lichen, confervæ, and various kinds of aquatic vegetables; and at the same time that the process of vegetable life is going on, the crystallizations of the calcareous matter, which is every where deposited, in consequence of the escape of carbonic acid, likewise proceed. — There is, I believe, no place in the world where there is a more striking example of the opposition or contrast of the laws of animate and inanimate nature, of the forces of inorganic chemical affinity, and those of the powers of life." *

The same observer informs us, that he fixed a stick in a mass of travertin covered by the water in the month of May, and in April following he had some difficulty in breaking, with a sharp pointed hammer, the mass which adhered to the stick, and which was several inches in thickness. The upper part was a mixture of light tufa and the leaves of confervæ: below this was a darker and more solid travertin, con-

* Consolations in Travel, pp. 123—125.

taining black and decomposed masses of confervæ; in the inferior part the travertin was more solid, and of a grey colour, but with cavities probably produced by the decomposition of vegetable matter.*

The stream which flows out of this lake fills a canal about nine feet broad and four deep, and is conspicuous in the landscape by a line of vapour which rises from it. It deposits calcareous tufa in this channel, and the Tiber probably receives from it, as well as from numerous other streams, much carbonate of lime in solution, which may contribute to the rapid growth of its delta. A large proportion of the most splendid edifices of ancient and modern Rome are built of travertin, derived from the quarries of Ponte Lucano, where there has evidently been a lake at a remote period, on the same plain as that already described. But the consideration of these would carry us beyond the times of history, and I shall conclude with one more example of the calcareous deposits of this neighbourhood,—those on the Anio.

Travertin of Tivoli.—The waters of the Anio incrust the reeds which grow on its banks, and the foam of the cataract of Tivoli forms beautiful pendant stalactites; but on the sides of the deep chasm into which the cascade throws itself, there is seen an extraordinary accumulation of horizontal beds of tufa and travertin, from four to five hundred feet in thickness. The section immediately under the temples of Vesta and the Sibyl, displays, in a precipice about four hundred feet high, some spheroids which are from *six to eight feet in diameter*, each concentric layer being about the eighth of an inch in thickness. The annexed

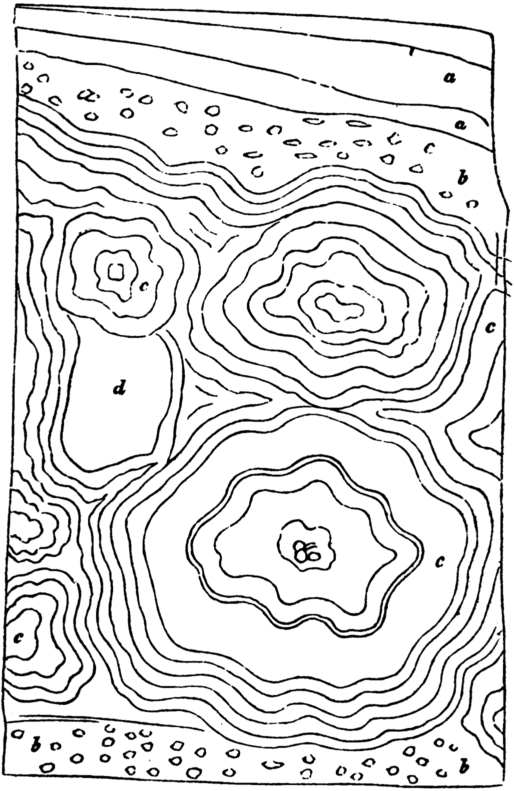
* Consolations in Travel, p. 127.

diagram exhibits about fourteen feet of this immense mass, as seen in the path cut out of the rock in descending from the temple of Vesta to the Grotto di Nettuno. I have not attempted to express in this drawing the innumerable thin layers of which these magnificent spheroids are composed, but the lines given mark some of the natural divisions into which they are separated by minute variations in the size or colour of the laminæ. The undulations also are much smaller, in proportion to the whole circumference, than in the drawing. The beds (*a a*) are of hard travertin and soft tufa; below them is a pisolite (*b*), the globules being of different sizes: underneath this appears a mass of concretionary travertin (*c c*), some of the spheroids being of the above-mentioned extraordinary size. In some places (as at *d*) there is a mass of amorphous limestone, or tufa, surrounded by concentric layers. At the bottom is another bed of pisolite (*b*), in which the small nodules are about the size and shape of beans, and some of them of filberts, intermixed with some smaller oolitic grains. In the tufaceous strata, wood is seen converted into a light tufa.

The following seems the most probable explanation of the origin of the rock in this singular position. The Anio flows through a deep irregular fissure or gorge in the Apennine limestone, which may have been caused by earthquakes. In this deep narrow channel there existed many small lakes, three of which have been destroyed, since the time of history, by the erosive action of the torrent, the last of them having remained down to the sixth century of our era.

We may suppose a similar lake of great depth to have existed at some remote period at Tivoli, and that, into this, the waters, charged with carbonate of

Fig. 16.



Section of spheroidal concretionary travertin under the Cascade of Tivoli.

lime, fell from a height inferior to that of the present cascade. Having, in their passage through the upper lakes, parted with their sand, pebbles, and coarse sediment, they only introduced into this lower pool drift-wood, leaves, and other buoyant substances. In seasons when the water was low, a deposit of ordinary

tufa, or of travertin, formed along the bottom; but at other times, when the torrent was swollen, the pool must have been greatly agitated, and every small particle of carbonate of lime which was precipitated, must have been whirled round again and again in various eddies, until it acquired many concentric coats, so as to resemble oolitic grains. If the violence of the motion be sufficient to cause the globule to be suspended for a sufficient length of time, it would grow to the size of a pea, or much larger. Small fragments of vegetable stems being incrusted on the sides of the stream, and then washed in, would form the nucleus of oval globules, and others of irregular shapes would be produced by the resting of fragments for a time on the bottom of the basin, where, after acquiring an unequal thickness of travertin on one side, they would again be set in motion. Sometimes globules, projecting above the general level of a stratum, would attract, by chemical affinity, other matter in the act of precipitation, and thus growing on all sides, with the exception of the point of contact, might at length form spheroids nearly perfect and many feet in diameter. Masses might increase above and below, so that a vertical section might afterwards present the phenomenon so common at Tivoli, where the nucleus of some of the concentric circles has the appearance of having been suspended, without support, in the water, until it became a spheroidal mass of great dimensions.

It is probable that the date of the greater portion of this calcareous formation may be anterior to the era of history, for we know that there was a great cascade at Tivoli in very ancient times; but, in the upper part of the travertin, is shown the hollow left by a wheel, in which the outer circle and the spokes

have been decomposed, and the spaces which they filled have been left void. It seems impossible to explain the position of this mould, without supposing that the wheel was imbedded before the lake was drained.

Calcareous springs in the Caucasus. — Pallas, in his journey along the Caucasus, a country now subject, from time to time, to be rent and fissured by violent earthquakes, enumerates a great many hot springs, which have deposited monticules of travertin precisely analogous in composition and structure to those of the baths of San Filippo and other localities in Italy. When speaking of the tophus-stone, as he terms these limestones, he often observes that it is *snow-white*, a description which is very applicable to the newer part of the deposit at San Filippo, where it has not become darkened by weathering. In many localities in the regions between the Caspian and Black Seas, where subterranean convulsions are frequent, travellers mention calc-sinter as an abundant product of hot springs. Near the shores of the Lake Urmia (or Maragha), for example, a marble which is much used in ornamental architecture, is rapidly deposited by a thermal spring.*

It is probable that some zoophytic and shelly limestones, which constitute coral reefs, may be supplied with carbonate of lime and other mineral ingredients from submarine springs, and that their heat, as well as their earthy and gaseous contents, may promote the development of corals, sponges, and testacea, just as vegetation is quickened by similar causes in the lake of the Solfatara before described. But of

* Von Hoff, Geschichte, &c. vol. ii. p. 114.

coral reefs and their probable origin I shall again have occasion to speak in the third book.

Sulphureous and gypseous springs.— The quantity of other mineral ingredients wherewith springs in general are impregnated, is insignificant in comparison to lime, and this earth is most frequently combined with carbonic acid. But, as sulphuric acid and sulphuretted hydrogen are very frequently supplied by springs, gypsum may, perhaps, be deposited largely in certain seas and lakes. The gypseous precipitates, however, hitherto known on the land, appear to be confined to a very few springs. Those at Baden, near Vienna, which feed the public bath, may be cited as examples. Some of these supply, singly, from 600 to 1000 cubic feet of water per hour, and deposit a fine powder, composed of a mixture of sulphate of lime with sulphur and muriate of lime.* In the Andes, at the Puenta del Inca, Lieutenant Brand found a thermal spring at the temperature of 91° F., containing a large proportion of gypsum with carbonate of lime and other ingredients.†

Siliceous springs. — *Azores.* — In order that water should hold a very large quantity of silica in solution, it seems necessary that it should be raised to a high temperature ‡; and as it may retain a greater heat under the pressure of the sea than in the atmosphere, submarine springs may, perhaps, be more charged with silex than any to which we have access. The hot springs of the Valle das Fernas, in the island of St. Michael, rising through volcanic rocks, precipitate

* C. Prevost, Essai sur la Constitution Physique du Bassin de ne, p. 10.

Travels across the Andes, p. 240.

aubeny on Volcanos, p. 222.

vast quantities of siliceous sinter, as it is usually termed. Around the circular basin of the largest spring, which is between twenty and thirty feet in diameter, alternate layers are seen of a coarser variety of sinter mixed with clay, including grass, ferns, and reeds, in different states of petrifaction. Wherever the water has flowed sinter is found, rising in some places eight or ten inches above the ordinary level of the stream. The herbage and leaves, more or less incrusted with silex, are said to exhibit all the successive steps of petrifaction, from the soft state to a complete conversion into stone; but in some instances, alumina, which is likewise deposited from the hot waters, is the mineralizing material. Branches of the same ferns which now flourish in the island are found completely petrified, preserving the same appearance as when vegetating, except that they acquire an ash-grey colour. Fragments of wood, and one entire bed from three to five feet in depth, composed of reeds now common in the island, have become completely mineralized.

The most abundant variety of siliceous sinter occurs in layers from a quarter to half an inch in thickness, accumulated on each other often to the height of a foot and upwards, and constituting parallel, and for the most part horizontal, strata many yards in extent. This sinter has often a beautiful semi-opalescent lustre. One of the varieties differs from that of Iceland and Ischia in the larger proportion of water it contains, and in the absence of alumina and lime. A recent breccia is also in the act of forming, composed of obsidian, pumice, and scoriæ, cemented by siliceous sinter.*

* Dr. Webster on the Hot Springs of Furnas, Ed. Phil. Journ. vol. vi. p. 306.

Geysers of Iceland. — But the hot springs in various parts of Iceland, particularly the celebrated geysers, afford the most remarkable example of the deposition of silex.* The circular reservoirs into which the geysers fall, are lined in the interior with a variety of opal, and round the edges with sinter. The plants incrusted with the latter substance have much the same appearance as those incrusted with calcareous tufa in our own country. They consist of various grasses, the horse-tail (*Equisetum*), and leaves of the birch tree, which are the most common of all, though no trees of this species now exist in the surrounding country. The petrified stems also of the birch occur in a state much resembling agatized wood.†

By analysis of the water, Mr. Faraday has ascertained that the solution of the silex is promoted by the presence of the alkali, soda. He suggests that the deposition of silica in an insoluble state takes place partly because the water when cooled by exposure to the air is unable to retain as much silica as when it issues from the earth at a temperature of 180° or 190° Fahr.; and partly because the evaporation of the water decomposes the compound of silica and soda which previously existed. This last change is probably hastened by the carbonic acid of the atmosphere uniting with the soda. The alkali, when disunited from the silica, would readily be dissolved in and removed by running water.‡

Ischia. — It has been found, by analysis, that several of the thermal waters of Ischia are impregnated with

* See a cut of the Icelandic geyser, Book II. chap. xx.

† M. Robert, Bullétin de la Soc. Géol. de France, tom. vii. p. 11.

‡ ...rrow's Iceland, p. 209.

a certain proportion of silica. Some of the hot vapours of that island are above the temperature of boiling water; and many fissures, near Monte Vico, through which the hot steam passes, are coated with a siliceous incrustation, first noticed by Dr. Thompson under the name of fiorite.

Ava, &c. — It has been often stated that the Danube has converted the external part of the piles of Trajan's bridge into silex; the Irawadi, in Ava, has been supposed, ever since the time of the Jesuit Padre Duchatz, to have the same petrifying power, as also Lough Neagh, in Ireland. Modern researches, however, in the Burman empire, have thrown doubt upon the lapidifying property of the Ava river *; there is certainly no foundation for the story in regard to Lough Neagh, and probably none in regard to the Danube.

Mineral waters, even when charged with a small proportion of silica, as those of Ischia, may supply certain species of corals, sponges, and infusoria, with matter for their siliceous secretions; but there is little doubt that rivers obtain silex in solution from another and far more general source, namely, the decomposition of felspar. When this mineral, which is so abundant an ingredient in the hypogene and trappean rocks, has disintegrated, it is found that the residue, called porcelain clay, contains a small proportion only of the silica which existed in the original felspar, the other part having been dissolved and removed by water. †

Ferruginous springs. — The waters of almost all springs contain some iron in solution; and it is a fact

* Dr. Buckland, Geol. Trans. second series, vol. ii. part iii. p. 384.

† See Elements of Geology; and Dr. Turner, Jam. Ed. New Phil. Journ. No. xxx. p. 246.

familiar to all, that many of them are so copiously impregnated with this metal, as to stain the rocks or herbage through which they pass, and to bind together sand and gravel into solid masses. We may naturally, then, conclude that this iron, which is constantly conveyed from the interior of the earth into lakes and seas, and which does not escape again from them into the atmosphere by evaporation, must act as a colouring and cementing principle in the subaqueous deposits now in progress. Geologists are aware that many ancient sandstones and conglomerates are bound together or coloured by iron.

Brine springs.—So great is the quantity of muriate of soda in some springs, that they yield one fourth of their weight in salt. They are rarely, however, so saturated, and generally contain, intermixed with salt, carbonate and sulphate of lime, magnesia, and other mineral ingredients. The brine springs of Cheshire are the richest in our country; those of Northwich being almost saturated. Those of Barton also, in Lancashire, and Droitwich in Worcestershire, are extremely rich.* They are known to have flowed for more than 1000 years, and the quantity of salt which they have carried into the Severn and Mersey must be enormous. These brine springs rise up through strata of sandstone and red marl, which contain large beds of rock salt. The origin of the brine, therefore, may be derived in this and many other instances from beds of fossil salt; but as muriate of soda is one of the products of volcanic emanations and of springs in volcanic regions, the original source of salt may be as deep seated as that of lava.

* L. Horner, Geol. Trans. vol. ii. p. 94.

The waters of the Dead Sea contain scarcely any thing except muriatic salt, which lends countenance, observes Dr. Daubeny, to the volcanic origin of the surrounding country, these salts being frequent products of volcanic eruptions. Many springs in Sicily contain muriate of soda, and the "fiume salso," in particular, is impregnated with so large a quantity, that cattle refuse to drink of it.

A hot spring, rising through granite, at Saint Nectaire, in Auvergne, may be mentioned as one of many, containing a large proportion of muriate of soda, together with magnesia and other ingredients. *

Carbonated springs. — *Auvergne.* — Carbonic acid gas is very plentifully disengaged from springs in almost all countries, but particularly near active or extinct volcanos. This elastic fluid has the property of decomposing many of the hardest rocks with which it comes in contact, particularly that numerous class in whose composition felspar is an ingredient. It renders the oxide of iron soluble in water, and contributes, as was before stated, to the solution of calcareous matter. In volcanic districts these gaseous emanations are not confined to springs, but rise up in the state of pure gas from the soil in various places. The Grotto del Cane, near Naples, affords an example, and prodigious quantities are now annually disengaged from every part of the Limagne d'Auvergne, where it appears to have been developed in equal quantity from time immemorial. As the acid is invisible, it is not observed, except an excavation be made, wherein it immediately accumulates, so that it will extinguish a candle. There are some springs in this district, where the water is seen bubbling and boiling up with much

* Annales de l'Auvergne, tome i. p. 234.

noise, in consequence of the abundant disengagement of this gas. The whole vegetation is affected, and many trees, such as the walnut, flourish more luxuriantly than they would otherwise do in the same soil and climate — the leaves probably absorbing carbonic acid. This gas is found in springs rising through the granite near Clermont, as well as in the tertiary limestones of the Limagne.* In the environs of Pont-Gibaud, not far from Clermont, a rock belonging to the gneiss formation, in which lead-mines are worked, has been found to be quite saturated with carbonic acid gas, which is constantly disengaged. The carbonates of iron, lime, and manganese are so dissolved, that the rock is rendered soft, and the quartz alone remains unattacked.† Not far off is the small volcanic cone of Chaluzet, which once broke up through the gneiss, and sent forth a lava-stream.

Disintegrating effects of carbonic acid. — The disintegration of granite is a striking feature of large districts in Auvergne, especially in the neighbourhood of Clermont. This decay was called by Dolomieu, "la maladie du granite;" and the rock may with propriety be said to have *the rot*, for it crumbles to pieces in the hand. The phenomenon may, without doubt, be ascribed to the continual disengagement of carbonic acid gas from numerous fissures.

In the plains of the Po, between Verona and Parma, especially at Villa Franca, south of Mantua, I observed great beds of alluvium, consisting chiefly of primary pebbles, percolated by spring water, charged with carbonate of lime and carbonic acid in great abundance. They are for the most part incrusted with calc-sinter:

* Le Coq, Annales de l'Auvergne, tome i. p. 217. May, 1828.
† Ann. Scient. de l'Auvergne, tome ii. June, 1829.

and the rounded blocks of gneiss, which have all the outward appearance of solidity, have been so disintegrated by the carbonic acid as readily to fall to pieces.

The subtraction of many of the elements of rocks by the solvent power of carbonic acid, ascending both in a gaseous state and mixed with spring-water in the crevices of rocks, must be one of the most powerful sources of those internal changes and re-arrangements of particles so often observed in strata of every age. The calcareous matter, for example, of shells, is often entirely removed and replaced by carbonate of iron, pyrites, silex, or some other ingredient, such as mineral waters usually contain in solution. It rarely happens, except in limestone rocks, that the carbonic acid can dissolve all the constituent parts of the mass; and for this reason, probably, calcareous rocks are almost the only ones in which great caverns and long winding passages are found.

Petroleum springs. — Springs impregnated with petroleum, and the various minerals allied to it, as bitumen, naphtha, asphaltum, and pitch, are very numerous, and are, in many cases, undoubtedly connected with subterranean fires, which raise or sublime the more subtle parts of the bituminous matters contained in rocks. Many springs in the territory of Modena and Parma, in Italy, produce petroleum in abundance; but the most powerful, perhaps, yet known, are those on the Irawadi, in the Burman empire. In one locality there are said to be 520 wells, which yield annually 400,000 hogsheads of petroleum.*

Fluid bitumen is seen to ooze from the bottom of

* Symes, Embassy to Ava, vol. ii. — Geol. Trans. second series, vol. ii. part iii. p. 388.

the sea, on both sides of the island of Trinidad, and to rise up to the surface of the water. Near Cape La Braye there is a vortex which, in stormy weather, according to Captain Mallet, gushes out, raising the water five or six feet, and covers the surface for a considerable space with petroleum, or tar; and the same author quotes Gumilla, as stating in his "Description of the Orinoco," that about seventy years ago, a spot of land on the western coast of Trinidad, near half way between the capital and an Indian village, sank suddenly, and was immediately replaced by a small lake of pitch, to the great terror of the inhabitants.*

Pitch lake of Trinidad. — It is probable that the great pitch lake of Trinidad owes its origin to a similar cause; and Dr. Nugent has justly remarked, that in that district all the circumstances are now combined from which deposits of pitch may have originated. The Orinoco has for ages been rolling down great quantities of woody and vegetable bodies into the surrounding sea, where, by the influence of currents and eddies, they may be arrested and accumulated in particular places. The frequent occurrence of earthquakes and other indications of volcanic action in those parts lend countenance to the opinion, that these vegetable substances may have undergone, by the agency of subterranean fire, those transformations and chemical changes which produce petroleum; and this may, by the same causes, be forced up to the surface, where, by exposure to the air, it becomes inspissated, and forms the different varieties of pure and earthy pitch, or asphaltum, so abundant in the island.†

* Dr. Nugent, Geol. Trans. vol. i. p. 69.

† Ibid. p. 67.

The bituminous shales, so common in geological formations of different ages, as also many stratified deposits of bitumen and pitch, seem clearly to attest that, at former periods, springs, in various parts of the world, were as commonly impregnated as now with bituminous matter, carried down, probably, by rivers into lakes and seas. It will, indeed, be easy to show that a large portion of the finer particles and the more crystalline substances, found in sedimentary rocks of different ages, are composed of the same elements as are now held in solution by springs, while the coarser materials bear an equally strong resemblance to the alluvial matter in the beds of existing torrents and rivers.

CHAPTER V.

REPRODUCTIVE EFFECTS OF RIVERS.

Division of deltas into lacustrine, mediterranean, and oceanic — Lake deltas — Growth of the delta of the Upper Rhone in the Lake of Geneva — Computation of the age of deltas — Recent deposits in Lake Superior — Deltas of inland seas — Rapid shallowing of the Baltic — Marine delta of the Rhone — Various proofs of its increase — Stony nature of its deposits — Delta of the Po, Adige, Isonzo, and other rivers entering the Adriatic — Rapid conversion of that gulf into land — Mineral characters of the new deposits — Delta of the Nile.

Having considered the destroying and transporting agency of running water, we have now to examine the reproductive effects of the same cause. To form a just conception of these effects will be more easy than to appreciate the excavating and removing force exerted by rivers and currents, for we shall now have the advantage of beholding in a palpable form the aggregate amount of matter which has accumulated at certain points in the lapse of ages. I shall therefore proceed to select some of the leading facts at present ascertained respecting the growth of deltas, and shall then offer some general observations on the quantity of sediment transported by rivers, and the manner of its distribution beneath the waters of lakes and seas.

Division of deltas into lacustrine, mediterranean, and oceanic. — Deltas may be divided into, first, those which are formed in lakes; secondly, those in inland

seas; and, thirdly, those on the borders of the ocean. The most characteristic distinction between the lacustrine and marine deltas consists in the nature of the organic remains which become imbedded in their deposits; for, in the case of a lake, it is obvious that these must consist exclusively of such genera of animals as inhabit the land or the waters of a river or lake; whereas, in the other case, there will be an admixture, and most frequently a predominance of animals which inhabit salt water. In regard, however, to the distribution of inorganic matter, the deposits of lakes and inland seas are formed under very analogous circumstances, and may be distinguished from those on the shores of the great ocean, where the tides cooperating with currents give rise to another class of phenomena. In lakes and inland seas, even of the largest dimensions, the tides are almost insensible, but the currents, as will afterwards appear, sometimes run with considerable velocity.

DELTAS IN LAKES.

Lake of Geneva.—It is natural to begin our examination with an inquiry into the new deposits in lakes, as they exemplify the first reproductive operations in which rivers are engaged when they convey the detritus of rocks and the ingredients of mineral springs from mountainous regions. The accession of new land at the mouth of the Rhone, at the upper end of the Lake of Geneva, or the Leman Lake, presents us with an example of a considerable thickness of strata which have accumulated since the historical era. This sheet of water is about thirty-seven miles long, and its breadth is from two to eight miles. The shape of the bottom

is very irregular, the depth having been found by late measurements to vary from 20 to 160 fathoms.* The Rhone, where it enters at the upper end, is turbid and discoloured; but its waters, where it issues at the town of Geneva, are beautifully clear and transparent. An ancient town, called Port Vallais (Portus Valesiæ of the Romans), once situated at the water's edge, at the upper end, is now more than a mile and a half inland — this intervening alluvial tract having been acquired in about eight centuries. The remainder of the delta consists of a flat alluvial plain, about five or six miles in length, composed of sand and mud, a little raised above the level of the river, and full of marshes.

Mr. De la Beche found, after numerous soundings in all parts of the lake, that there was a pretty uniform depth of from 120 to 160 fathoms throughout the central region, and, on approaching the delta, the shallowing of the bottom began to be very sensible at a distance of about a mile and three quarters from the mouth of the Rhone; for a line drawn from St. Gingoulph to Vevey, gives a mean depth of somewhat less than 600 feet, and from that part to the Rhone, the fluviatile mud is always found along the bottom.† We may state, therefore, that the new strata annually produced are thrown down upon a slope about two miles in length; so that, notwithstanding the great depth of the lake, the new deposits are not inclined at a high angle; the dip of the beds, indeed, is so slight, that they would be termed, in ordinary geological language, horizontal.

The strata probably consist of alternations of finer and coarser particles; for, during the hotter months

* De la Beche, Ed. Phil. Journ. vol. ii. p. 107. Jan. 1820.

† De la Beche, MS.

from April to August, when the snows melt, the volume and velocity of the river are greatest, and large quantities of sand, mud, vegetable matter, and drift-wood are introduced; but, during the rest of the year, the influx is comparatively feeble, so much so, that the whole lake, according to Saussure, stands six feet lower. If, then, we could obtain a section of the accumulation formed in the last eight centuries, we should see a great series of strata, probably from 600 to 900 feet thick (the supposed original depth of the head of the lake), and nearly two miles in length, inclined at a very slight angle. In the mean time, a great number of smaller deltas are growing around the borders of the lake, at the mouths of rapid torrents, which pour in large masses of sand and pebbles. The body of water in these torrents is too small to enable them to spread out the transported matter over so extensive an area as the Rhone does. Thus, for example, there is a depth of eighty fathoms within half a mile of the shore, immediately opposite the great torrent which enters east of Ripaille, so that the dip of the strata in that minor delta must be about four times as great as those deposited by the main river at the upper extremity of the lake.*

Chronological computations of the age of deltas. — The capacity of this basin being now ascertained, it would be an interesting subject of inquiry, to determine in what number of years the Leman Lake will be converted into dry land. It would not be very difficult to obtain the elements for such a calculation, so as to approximate at least to the quantity of time required for the accomplishment of the result. The number of

* De la Beche, MS.

cubic feet of water annually discharged by the river into the lake being estimated, experiments might be made in the winter and summer months, to determine the proportion of matter held in suspension or in chemical solution by the Rhone. It would be also necessary to allow for the heavier matter drifted along at the bottom, which might be estimated on hydrostatical principles, when the average size of the gravel and the volume and velocity of the stream at different seasons were known. Supposing all these observations to have been made, it would be more easy to calculate the future than the former progress of the delta, because it would be a laborious task to ascertain, with any degree of precision, the original depth and extent of that part of the lake which is already filled up. Even if this information were actually obtained by borings, it would only enable us to approximate within a certain number of centuries to the time when the Rhone began to form its present delta; but this would not give us the date of the origin of the Leman Lake in its present form, because the river may have flowed into it for thousands of years, without importing any sediment whatever. Such would have been the case, if the waters had first passed through a chain of upper lakes; and that this was actually the fact, is indicated by the course of the Rhone between Martigny and the Lake of Geneva, and, still more decidedly, by the channels of many of its principal feeders.

If we ascend, for example, the valley through which the Dranse flows, we find that it consists of a succession of basins, one above the other, in each of which there is a wide expanse of flat alluvial lands, separated from the next basin by a rocky gorge, once evidently the barrier of a lake. The river has filled these lakes, one

after the other, and has partially cut through the barriers, which it is still gradually eroding to a greater depth. The examination of almost all valleys in mountainous districts affords similar proofs of the obliteration of a series of lakes, by the filling up of hollows and the cutting through of rocky barriers — a process by which running water ever labours to produce a more uniform declivity. Before, therefore, we can pretend even to hazard a conjecture as to the era at which any particular delta commenced, we must be thoroughly acquainted with the geographical features and geological history of the whole system of higher valleys which communicate with the main stream, and all the changes which they have undergone since the last series of convulsions which agitated and altered the face of the country.

Lake Superior. — Lake Superior is the largest body of fresh water in the world, being above 1700 geographical miles in circumference when we follow the sinuosities of its coasts, and its length, on a curved line drawn through its centre, being more than 400, and its extreme breadth above 150 geographical miles. Its surface is nearly as large as the whole of England. Its average depth varies from 80 to 150 fathoms; but, according to Captain Bayfield, there is reason to think that its greatest depth would not be overrated at 200 fathoms *, so that its bottom is, in some parts, nearly 600 feet below the level of the Atlantic, its surface about as much above it. There are appearances in different parts of this, as of the other Canadian lakes, leading us to infer that its waters formerly occupied a much higher level than they reach at present; for at a considerable distance from the present shores,

* Trans. of Lit. and Hist. Soc. of Quebec, vol. i. p. 5. 1829.

parallel lines of rolled stones and shells are seen rising one above the other, like the seats of an amphitheatre. These ancient lines of shingle are exactly similar to the present beaches in most bays, and they often attain an elevation of 40 or 50 feet above the present level.

As the heaviest gales of wind do not raise the waters more than three or four feet *, the elevated beaches must either be referred to the subsidence of the lake at former periods, in consequence of the wearing down of its barrier, or to the upraising of the shores by earthquakes, like those which have produced similar phenomena on the coast of Chili. The streams which discharge their waters into Lake Superior are several hundred in number, without reckoning those of smaller size; and the quantity of water supplied by them is many times greater than that discharged at the Falls of St Mary, the only outlet. The evaporation, therefore, is very great, and such as might be expected from so vast an extent of surface.

On the northern side, which is encircled by primary mountains, the rivers sweep in many large boulders with smaller gravel and sand, chiefly composed of granitic and trap rocks. There are also currents in the lake in various directions, caused by the continued prevalence of strong winds, and to their influence we may attribute the diffusion of finer mud far and wide over great areas; for, by numerous soundings made

* Captain Bayfield remarks, that Dr. Bigsby, to whom we are indebted for several communications respecting the geology of the Canadian lakes, was misinformed by the fur traders in regard to the extraordinary height (twenty or thirty feet) to which he asserts that the autumnal gales will raise the water of Lake Superior. — Trans. of Lit. and Hist. Soc. of Quebec, vol. i. p. 7. 1829,

during the late survey, it was ascertained that the bottom consists generally of a very adhesive clay, containing shells of the species at present existing in the lake. When exposed to the air, this clay immediately becomes indurated in so great a degree, as to require a smart blow to break it. It effervesces slightly with diluted nitric acid, and is of different colours in different parts of the lake; in one district blue, in another red, and in a third white, hardening into a substance resembling pipe-clay.* From these statements, the geologist will not fail to remark how closely these recent lacustrine formations in America resemble the tertiary argillaceous and calcareous marls of lacustrine origin in Central France. In both cases many of the genera of shells most abundant, as Limnea and Planorbis, are the same; and in regard to other classes of organic remains there must be the closest analogy, as I shall endeavour more fully to explain when speaking of the imbedding of plants and animals in recent deposits.

DELTAS OF INLAND SEAS.

Baltic.—Having thus briefly considered some of the lacustrine deltas now in progress, we may next turn our attention to those of inland seas.

The shallowing and conversion into land of many parts of the Baltic, especially the Gulfs of Bothnia and Finland, have been demonstrated by a series of accurate observations, for which we are in a great measure indebted to the animated controversy which has been kept up, since the middle of the last century, concerning the gradual lowering of the level of the Baltic. I shall revert to this subject when treating of the slow

* Trans. of Lit. and Hist. Soc. of Quebec, vol. i. p. 5. 1829.

and insensible upheaving of the land in certain parts of Sweden, a movement which produces an apparent fall in the level of the waters, both of the Baltic and the ocean.* It is only necessary to state in this place, that the rapid gain of low tracts of land near Torneo, Piteo, and Luleo, near the head of the Gulf of Bothnia, are due to the joint operation of two causes — the influx of sediment from numerous rivers, and a slow and general upward movement of the land itself, and bed of the sea, at the rate of several feet in a century.

Delta of the Rhone. — We may now turn our attention to some of the principal deltas of the Mediterranean, for no other inland sea affords so many examples of accessions of new land at the mouths of rivers within the records of authentic history. The lacustrine delta of the Rhone in Switzerland has already been considered, and its contemporaneous marine delta may now be described. Scarcely has the river passed out of the Lake of Geneva, before its pure waters are again filled with sand and sediment by the impetuous Arve, descending from the highest Alps, and bearing along in its current the granitic detritus annually brought down by the glaciers of Mont Blanc. The Rhone afterwards receives vast contributions of transported matter from the Alps of Dauphiny, and the primary and volcanic mountains of Central France; and when at length it enters the Mediterranean, it discolours the blue waters of that sea with a whitish sediment, for the distance of between six and seven miles,

* Since writing the third edition, I have visited Sweden, and removed the doubts which I before entertained and expressed respecting the alleged gradual elevation of the land in Scandinavia. — See Book II. chap. xviii.

throughout which space the current of fresh water is perceptible.

Proofs of its increase since historical periods.—Strabo's description of the delta is so inapplicable to its present configuration, as to attest a complete alteration in the physical features of the country since the Augustan age. It appears, however, that the head of the delta, or the point at which it begins to ramify, has remained unaltered since the time of Pliny, for he states that the Rhone divided itself at Arles into two arms. This is the case at present; one of the branches, the western, being now called Le Petit Rhône, which is again subdivided before entering the Mediterranean. The advance of the base of the delta, in the last eighteen centuries, is demonstrated by many curious antiquarian monuments. The most striking of these is the great and unnatural détour of the old Roman road from Ugernum to Beziers (*Bœterræ*) which went round by Nismes (*Nemausus*). It is clear that, when this was first constructed, it was impossible to pass in a direct line as now, across the delta, and that either the sea or marshes intervened in a tract now consisting of terra firma.* Astruc also remarks, that all the places on low lands, lying to the north of the old Roman road between Nismes and Beziers, have names of Celtic origin, evidently given to them by the first inhabitants of the country; whereas, the places lying south of that road, towards the sea, have names of Latin derivation, and were clearly founded after the Roman language had been introduced.

Another proof, also, of the great extent of land which has come into existence since the Romans con-

* Mém. d'Astruc, cited by Von Hoff, vol. i. p. 288.

quered and colonized Gaul, is derived from the fact, that the Roman writers never mention the thermal waters of Balaruc in the delta, although they were well acquainted with those of Aix, and others still more distant, and attached great importance to them, as they invariably did to all hot springs. The waters of Balaruc, therefore, must have formerly issued under the sea —a common phenomenon on the borders of the Mediterranean; and on the advance of the delta they continued to flow out through the new deposits.

Among the more direct proofs of the increase of land, we find that Mese, described under the appellation of Mesua Collis by Pomponius Mela *, and stated by him to be nearly an island, is now far inland. Notre Dame des Ports, also, was a harbour in 898, but is now a league from the shore. Psalmodi was an island in 815, and is now two leagues from the sea. Several old lines of towers and sea-marks occur at different distances from the present coast, all indicating the successive retreat of the sea, for each line has in its turn become useless to mariners; which may well be conceived, when we state that the tower of Tignaux, erected on the shore so late as the year 1737, is already a mile remote from it. †

By the confluence of the Rhone and the currents of the Mediterranean, driven by winds from the south, sand-bars are often formed across the mouths of the river: by these means considerable spaces become divided off from the sea, and subsequently from the river also, when it shifts its channels of efflux. As some of these lagoons are subject to the occasional

* Lib. ii. c. v.

† Bouche, Chorographie et Hist. de Provence, vol. i. p. 23., cited by Von Hoff, vol. i. p. 290.

ingress of the river when flooded, and of the sea during storms, they are alternately salt and fresh. Others, after being filled with salt water, are often lowered by evaporation till they become more salt than the sea; and it has happened, occasionally, that a considerable precipitate of muriate of soda has taken place in these natural salterns. During the latter part of Napoleon's career, when the excise laws were enforced with extreme rigour, the police was employed to prevent such salt from being used. The fluviatile and marine shells enclosed in these small lakes often live together in brackish water; but the uncongenial nature of the fluid usually produces a dwarfish size, and sometimes gives rise to strange varieties in form and colour.

Captain Smyth, in his survey of the coast of the Mediterranean, found the sea, opposite the mouth of the Rhone, to deepen gradually from four to forty fathoms, within a distance of six or seven miles, over which the discoloured fresh water extends; so that the inclination of the new deposits must be too slight to be appreciable in such an extent of section as a geologist usually obtains in examining ancient formations. When the wind blew from the south-west, the ships employed in the survey were obliged to quit their moorings; and when they returned, the new sand-banks in the delta were found covered over with a great abundance of marine shells. By this means, we learn how occasional beds of drifted marine shells may become interstratified with freshwater strata at a river's mouth.

Stony nature of its deposits. — That a great proportion, at least, of the new deposit in the delta of the Rhone consists of *rock*, and not of loose incoherent

matter, is perfectly ascertained. In the Museum at Montpellier is a cannon taken up from the sea near the mouth of the river, imbedded in a crystalline calcareous rock. Large masses, also, are continually taken up of an arenaceous rock, cemented by calcareous matter including multitudes of broken shells of recent species. The observations lately made on this subject corroborate the former statement of Marsilli, that the earthy deposits of the coast of Languedoc form a stony substance, for which reason he ascribes a certain bituminous, saline, and glutinous nature to the substances brought down with sand by the Rhone.* If the number of mineral springs charged with carbonate of lime which fall into the Rhone and its feeders in different parts of France be considered, we shall feel no surprise at the lapidification of the newly deposited sediment in this delta. It should be remembered, that the fresh water introduced by rivers being lighter than the water of the sea, floats over the latter, and remains upon the surface for a considerable distance. Consequently, it is exposed to as much evaporation as the waters of a lake; and the area over which the river-water is spread, at the junction of great rivers and the sea, may well be compared, in point of extent, to that of considerable lakes.

Now, it is well known, that so great is the quantity of water carried off by evaporation in some lakes, that it is nearly equal to the water flowing in; and in some inland seas, as the Caspian, it is quite equal. We may, therefore, well suppose, that, in cases where a strong current does not interfere, the greater portion not only of the matter held mechanically in suspension,

* Hist. Phys. de la Mer.

but of that also which is in chemical solution, may be precipitated at no great distance from the shore. When these finer ingredients are extremely small in quantity, they may only suffice to supply crustaceous animals, corals, and marine plants, with the earthy particles necessary for their secretions; but whenever it is in excess (as generally happens if the basin of a river lie partly in a district of active or extinct volcanos), then will solid deposits be formed, and the shells will at once be included in a rocky mass.

Delta of the Po. — The Adriatic presents a great combination of circumstances favourable to the rapid formation of deltas — a gulf receding far into the land — a sea without tides or strong currents, and the influx of two great rivers, the Po and the Adige, besides numerous minor streams, draining on the one side a great crescent of the Alps, and on the other some of the loftiest ridges of the Apennines. From the northernmost point of the Gulf of Trieste, where the Isonzo enters, down to the south of Ravenna, there is an uninterrupted series of recent accessions of land, more than 100 miles in length, which within the last 2000 years have increased from *two to twenty miles in breadth.* The Isonzo, Tagliamento, Piave, Brenta, Adige, and Po, besides many other inferior rivers, contribute to the advance of the coast-line, and to the shallowing of the gulf. The Po and the Adige may now be considered as entering by one common delta, for two branches of the Adige are connected with arms of the Po.

In consequence of the great concentration of the flooded waters of these streams since the system of embankment became general, the rate of encroachment of the new land upon the Adriatic, especially at

that point where the Po and Adige enter, is said to have been greatly accelerated. Adria was a seaport in the time of Augustus, and had, in ancient times, given its name to the gulf; it is now about twenty Italian miles inland. Ravenna was also a seaport, and is now about four miles from the main sea. Yet even before the practice of embankment was introduced, the alluvium of the Po advanced with rapidity on the Adriatic; for Spina, a very ancient city, originally built in the district of Ravenna, at the mouth of a great arm of the Po, was, so early as the commencement of our era, eleven miles distant from the sea.*

The greatest depth of the Adriatic, between Dalmatia and the mouths of the Po, is twenty-two fathoms; but a large part of the Gulf of Trieste and the Adriatic, opposite Venice, is less than twelve fathoms deep. Farther to the south, where it is less affected by the influx of great rivers, the gulf deepens considerably. Donati, after dredging the bottom, discovered the new deposits to consist partly of mud and partly of rock, the rock being formed of calcareous matter, incrusting shells. He also ascertained, that particular species of testacea were grouped together in certain places, and were becoming slowly incorporated with the mud, or calcareous precipitates.† Olivi, also, found some deposits of sand, and others of mud, extending half way across the gulf; and he states that their distribution along the bottom was evidently determined by the prevailing current.‡ It is probable, therefore, that the finer sediment of all the rivers at the head of the

* See Brocchi on the various writers on this subject. Conch. Foss. Subap. vol. i. p. 118.

† Ibid. vol. i. p. 39.

‡ Ibid. vol. ii. p. 94.

Adriatic may be intermingled by the influence of the current; and all the central parts of the gulf may be considered as slowly filling up with horizontal deposits, similar to those of the Subapennine hills, and containing many of the same species of shells. The Po merely introduces at present fine sand and mud; for it carries no pebbles farther than the spot where it joins the Trebia, west of Piacenza. Near the northern borders of the basin, the Isonzo, Tagliamento, and many other streams, are forming immense beds of sand and some conglomerate; for here some high mountains of Alpine limestone approach within a few miles of the sea.

In the time of the Romans, the hot-baths of Monfalcone were on one of several islands of Alpine limestone, between which and the mainland, on the north, was a channel of the sea, about a mile broad. This channel is now converted into a grassy plain, which surrounds the islands on all sides. Among the numerous changes on this coast, we find that the present channel of the Isonzo is several miles to the west of its ancient bed, in part of which, at Ronchi, the old Roman bridge which crossed the Via Appia was lately found buried in fluviatile silt.

Notwithstanding the present shallowness of the Adriatic, it is highly probable that its original depth was very great; for if all the low alluvial tracts were taken away from its borders and replaced by sea, the high land would terminate in that abrupt manner which generally indicates, in the Mediterranean, a great depth of water near the shore, except in those spots where sediment imported by rivers and currents has diminished the depth. Many parts of the Mediterranean are now ascertained to be above 2000

feet deep, close to the shore, as between Nice and Genoa; and even sometimes 6000 feet, as near Gibraltar. When, therefore, we find near Parma, and in other districts in the interior of the Italian peninsula, beds of horizontal tertiary marl attaining a thickness of about 2000 feet, or when we discover strata of inclined conglomerate, of the same age, near Nice, measuring above a thousand feet in thickness, and extending seven or eight miles in length, we behold nothing which the analogy of the deltas in the Adriatic might not lead us to anticipate.

Coast of Asia Minor.—Examples of the advance of the land upon the sea are afforded by the southern coast of Asia Minor. Captain Beaufort has pointed out in his Survey the great alterations effected since the time of Strabo, where havens are filled up, islands joined to the mainland, and where the whole continent has increased many miles in extent. Strabo himself, on comparing the outline of the coast in his time with its ancient state, was convinced, like our countryman, that it had gained very considerably upon the sea. The new-formed strata of Asia Minor consist *of stone*, not of loose, incoherent materials. Almost all the streamlets and rivers, like many of those in Tuscany and the south of Italy, hold abundance of carbonate of lime in solution, and precipitate travertin, or sometimes bind together the sand and gravel into solid sandstones and conglomerates: every delta and sand bar thus acquires solidity, which often prevents streams from forcing their way through them, so that their mouths are constantly changing their position.*

* Karamania, or a brief Description of the Coast of Asia Minor, &c. London, 1817.

Delta of the Nile. — That Egypt was "the gift of the Nile," was the opinion of her priests before the time of Herodotus; and Rennell observes, that the "configuration and composition of the low lands leave no room for doubt that the sea once washed the base of the rocks on which the pyramids of Memphis stand, the *present* base of which is washed by the inundation of the Nile, at an elevation of 70 or 80 feet above the Mediterranean. But when we attempt to carry back our ideas to the remote period when the foundation of the delta was first laid, we are lost in the contemplation of so vast an interval of time."* Herodotus observes, "that the country round Memphis seemed formerly to have been an arm of the sea gradually filled by the Nile, in the same manner as the Meander, Achelous, and other streams, had formed deltas. Egypt, therefore, he says, like the Red Sea, was once a long narrow bay, and both gulfs were separated by a small neck of land. If the Nile, he adds, should by any means have an issue into the Arabian Gulf, it might choke it up with earth in 20,000, or even, perhaps, in 10,000 years; and why may not the Nile have filled with mud a still greater gulf in the space of time which has passed before our age?"†

The bed of the river itself, says Sir J. G. Wilkinson, undergoes a gradual increase of elevation, varying in different places, and always lessening in proportion as the river approaches the sea. "This increase of elevation in perpendicular height is much smaller in Lower than in Upper Egypt; and in the delta it diminishes still more; so that, according to an approximate calculation, the land about Elephan-

* Geog. Syst. of Herod. vol. ii. p. 107. † Euterpe, XI.

tine, or the first cataract, lat. 24° 5′, has been raised nine feet in 1700 years; at Thebes, lat. 25° 43′, about seven feet; and at Heliopolis and Cairo, lat. 30°, about five feet ten inches. At Rosetta and the mouths of the Nile, lat. 31° 30′, the diminution in the perpendicular thickness of the deposit is lessened in a much greater decreasing ratio than in the straitened valley of Central and Upper Egypt, owing to the great extent, east and west, over which the inundation spreads." *

For this reason the alluvial deposit does not cause the delta to protrude rapidly into the sea, although some ancient cities are now a mile or more inland, and the mouths of the Nile, mentioned by the earlier geographers, have been many of them silted up, and the outline of the coast entirely changed.

Homer has stated that "the distance from the Isle of Pharos to Ægyptus was as much as a vessel with a fair wind could perform in one day," whereas this island is now close to the shore, and united with it by an artificial dyke. Strabo and others explained this by supposing the progress of the delta since the days of Homer to have connected the island with the continent †; but Sir J. Wilkinson remarks that Homer has often used the word Ægyptus to signify the Nile; and he merely meant that Pharos was distant one day's sail from that river, or its principal mouth.

The bed of the Nile always keeps pace with the general elevation of the soil, and the banks of this river, like those of the Mississippi and its tributaries (see p. 353.), are much higher than the flat land at a distance, so that they are seldom covered during the highest inun-

* Journ. of Roy. Geograph. Soc. vol. ix. p. 432.

† Lib. I. part i. pp. 80. 98.

dations. In consequence of the gradual rise of the river's bed, the annual flood is constantly spreading over a wider area, and the alluvial soil encroaches on the desert, covering, to the depth of six or seven feet, the base of statues and temples which the waters never reached 3000 years ago. Although the sands of the Libyan deserts have in some places been drifted into the valley of the Nile, yet these aggressions, says Wilkinson, are far more than counterbalanced by the fertilizing effect of the water which now reaches farther inland towards the desert, so that the number of square miles of arable soil is greater at present than at any previous period.

Mud of the Nile. — The analysis of this mud gives nearly one half of argillaceous earth, and about one fourth of carbonate of lime, nearly one tenth of carbon, the remainder consisting of water, silex, oxide of iron, and carbonate of magnesia.*

In many places, as at Cairo, where artificial excavations have been made, or where the river has undermined its banks, the mud is seen to be thinly stratified, the upper part of each annual layer consisting of earth of a lighter colour than the lower, and the whole separating easily from the deposit of the succeeding year. These annual layers are variable in thickness; but, according to the calculations of Girard and Wilkinson, the mean annual thickness of a layer at Cairo cannot exceed that of a sheet of thin pasteboard, and a stratum of two or three feet must represent the accumulation of a thousand years.

The depth of the Mediterranean is about twelve fathoms at a small distance from the shore of the

* Girard, Mém. sur l'Egypte, tome i. pp. 348. 382.

delta; it afterwards increases gradually to 50, and then suddenly descends to 380 fathoms, which is, perhaps, the original depth of the sea where it has not been rendered shallower by fluviatile matter. The progress of the delta in the last 2000 years affords, perhaps, no measure for estimating its rate of growth when it was an inland bay, and had not yet protruded itself beyond the coast-line of the Mediterranean. A powerful current now sweeps along the shores of Africa, from the Straits of Gibraltar to the prominent convexity of Egypt, the western side of which is continually the prey of the waves; so that not only are fresh accessions of land checked, but ancient parts of the delta are carried away. By this cause Canopus and some other towns have been overwhelmed; but to this subject I shall again refer when speaking of tides and currents.

END OF THE FIRST VOLUME.

London:
Printed by A. Spottiswoode,
New-Street-Square.

[illegible]; it affirm[illegible]
[illegible]ly dev[illegible]
[illegible] original
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]